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TRANSACTIONS

OF THE

GEOLOGICAL SOCIETY OF GLASGOW.

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TRANSACTIONS

OF THE

GEOLOGICAL SOCIETY

OF GLASGOW.

VOL. XVI.

1916-1918.

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TRANSACTIONS

OF THE

GEOLOGICAL SOCIETY OF GLASGOW.

No. I.—The Geological Factors Affecting the Strategy of the War and the Geology of the Potash Salts. By Professor J. W. Gregory, D.Sc., F.R.S.

[Presidential Address, delivered 14th October, 1915. Issued separately, 5th September, 1916.]

The use of war, said Disraeli, is to teach people geography. It may also be used, though its lessons are terribly expensive, to teach geology, for many wars are occasioned and settled by geological factors. That geographical conditions control international relations is well understood; but the political effects of geological influences are less widely recognised. Nevertheless it is in consequence of the geological structure of the Continent that Belgium has again suffered as the cockpit of Europe, that Poland is threatened with a fourth partition, that the Russian advance was directed toward the fields of Kutusov's struggles with Napoleon and the Italian towards the war-worn route of the Brenner, that France is struggling so heroically to repeat her achievement of 1794 by again expelling the Prussians from the Vosges, and that once more the East and West have renewed their conflict on former battlefields in our effort to wrest the Dardanelles from the impracticable but chivalrous Turk.

When the Peace Congress assembles, its meeting-room might be appropriately provided with a geological map of Europe and Western Asia, since the resettlement of the frontiers will be largely dependent on geological influences, of which the diplomatists may have no conscious knowledge. It is the geological

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structure of Europe, supplemented by climatic influences, that has fixed the sites of the chief industrial centres, settled the main routes of international communications, determined the distribution and moulded the characters of the European peoples. Geological factors are the ultimate reason why—

On the old battleground,
Where fought your fathers,
Faithful shall ye be found
When the storm gathers.—*C. W. Brodribb.*

The geological structure of Europe has determined its relief and also the distribution of the mineral resources upon which so largely rests the prosperity of the industrial nations. The irregular distribution of those minerals depends on the geological history of the Continent. Europe includes four chief divisions —the Alpine axis with its southern loops, the Great Plain, the northern highlands, and the southern basins. The Alpine axis crosses the Continent from east to west, and includes the Pyrenees, Alps, Carpathians, and Caucasus; and to the south of this axis are various southern loops, including the Apennines, Atlas, Sierra Nevada of Spain, and the chief mountains of the Balkan Peninsula. The Great Plain lies to the north of the mountain axis and extends from the English Midlands across Holland and Germany into Russia, where it widens until it ranges from the Arctic Ocean to the Black Sea. The Great Plain is interrupted in Germany by hills of ancient rocks which rise above it like islands. The northern highlands —Scandinavia, Finland, and the Scottish Highlands—are fragments of an ancient land, and consist, as a whole, of the oldest rocks in Europe. To the south of the Alpine axis is a series of basins, some of which, such as the plain of Hungary, are sunklands; in others the floors have sunk beneath the sea, and thus given rise to the various basins of the Mediterranean.

The origin of these geographical divisions may be summarised as follows:—The Alpine axis consists of a belt of the earth's crust which was crumpled into mountains by intense pressure acting mostly from south to north; the folds thus formed advanced like waves against some strong blocks of old rocks, and their resistance protected the Great Plain from the movements that convulsed the Alpine axis. Earth washed from the moun-

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tains was spread over the low country, and thus formed the rich agricultural lands of the Great Plain.

The northward movement of the land during the formation of the Alpine axis left wide southern areas inadequately supported, and they collapsed into sunklands and inland seas.

Each of these four physical divisions has its own special mineral deposits. The old rocks of the northern highlands contain practically neither coal nor oil, but they have scattered ore deposits, especially of iron, copper, and lead. These and the economic minerals of the Alpine mountains are of secondary importance. The movements that formed the mountains have, however, played a very important part in the development of the mineral industries of Europe. The most important mining fields are on the Great Plain. The chief metallic ores are in the blocks of old rocks which rise through the Great Plain or form the uplands beside it; and the main supplies of coal, oil, and salt are in the beds which were folded during the Alpine movements, and have thus been brought repeatedly to the surface, and rendered available for mining in many localities.

The subsidences to the south of the Alpine line had the opposite effect, for owing to them the areas in southern Europe which were most likely to have contained coal-fields sank beneath the sea. The loss of these minerals is not adequately compensated by those left accessible in the Mediterranean lands. Thus the goldfields of Servia, which were worked by the Romans on a colossal scale, when tested in modern times have proved so poor that they could only have paid as they were worked by slaves fed on slave-grown rice. The vast stores of iron ores in Spain and along the Mediterranean, like the Algerian phosphates, are only worked where they can be mined cheaply and easily transported to the coal-fields of northern Europe.

The Coal-Fields in the War Area.

Coal is the most important mineral to a nation, as it is the most convenient of fuels, and contains invaluable though long-wasted by-products. One of the most important influences on the redistribution of political power in Europe during the past forty years has been the discovery that Germany, instead of being comparatively poor in coal, is one of the greatest coal

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countries of the world. In 1870 Germany produced (exclusive of 6,000,000 tons of brown coal) 23,000,000 tons of bituminous coal. The British production was then 110,000,000 tons. By 1913 Germany had raised her output of bituminous coal to 191,500,000 tons, in addition to 87,000,000 tons of brown coal. Our own magnificent output had grown to 287,500,000 tons. Hence since 1870 we have increased our coal output two and a half times; but Germany has multiplied hers eightfold.

Even more significant than the increase in the coal production of Germany is the discovery of the vastness of her coal reserves. According to the estimates submitted in 1913 to the International Geological Congress (1913, vol. i., pp. xxviii.-xxxvii.), the total reserves of coal in Europe are 784,000,000,000 tons (excluding lignite), and of this amount Germany is credited with 423,000,000,000 tons, or considerably more than half. The reserves of coal, excluding the lignites, of the British Isles, France, Russia, and Germany are shown on the following table:—

	IN MILLION TONS.		
	Actual Reserves.	Probable Reserves.	Total.
British Isles, - -	141,000	48,000	189,000
Germany, - - -	95,000	315,000	410,000
France, - - -	4,000	12,000	16,000
Russia, - - -	57	58,000	58,057

Hence it appears that the German reserves of bituminous coal are more than twice as large as our own. We have the advantage of larger supplies of anthracite, of which Germany contains but little; and our actual reserves of coal are the larger. The German superiority is in the "probable reserves," of which ours, it may be, have been underestimated owing to more cautious calculations. It would, however, be unwise to rely on this possibility. In coal Germany is the most richly endowed of European countries. The significance of that pregnant fact does not seem to have been adequately recognised.

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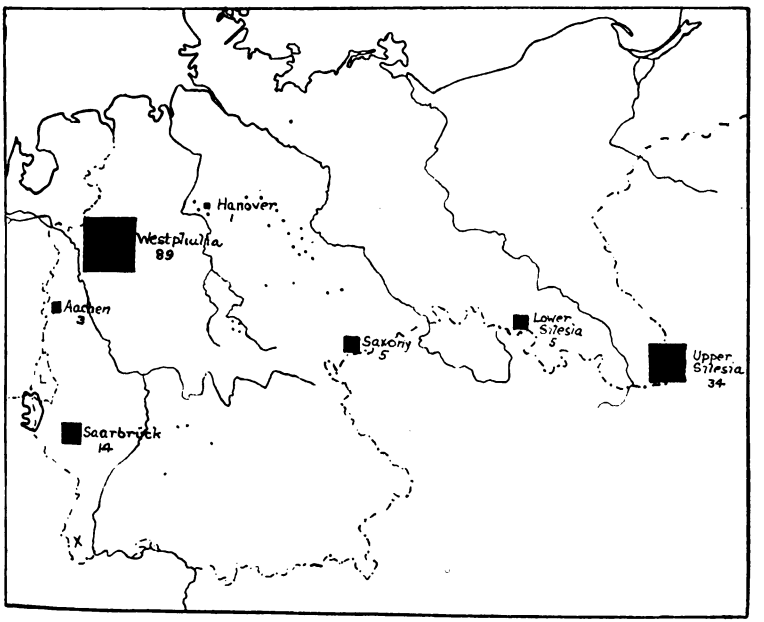
The abundance of coal in Germany helps to explain her rapid industrial development, and the distribution of the coal-fields shows why she requires an army always ready for instant battle. The coal-fields are most unfortunately placed from the point of view of German strategy. Excepting the smallest, which is to the east of the Weser, they are all situated in exposed positions near the frontiers. This fact is illustrated by Fig. 1. The most important coal-field—for it yields 59



Figures in Million Tons.

SKETCH-MAP.

Fig. 1.—The German Coal-Fields, showing—

(1) By black squares the German Coal-Fields and their Relative Output in 1910 (excluding Lignite).

(2) By thick black line the outline of the Lorraine Iron-Field.

(3) By black dots the chief German Potash Works.

(4) By a cross the Potash Field of Upper Alsace.

per cent. of the total German output of bituminous coal—is in Westphalia, a little east of the open Dutch frontier. Germany

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would have no strong natural defence for her richest coal-field if Holland joined a coalition against her.

The second coal-field in order of importance is in the south-eastern corner of Silesia. It is near the frontier of Russia, Austria, and Bohemia, and is especially exposed to attack from Russia.

The third coal-field, that of Saarbrück, is near the frontier of Lorraine, and part of it was French for a couple of centuries before 1871. It and the smaller coal-field of Aachen, which is about 3 miles from Belgium and Holland, are both dangerously near the western frontier. The fields of bituminous coal in south-western Saxony and Lower Silesia are both near the frontier of Bohemia. They are no doubt safe from attack during the alliance with Austria, but if it lapsed or if Bohemia became an independent Slav State these coal-fields would be in a very exposed position. The only German bituminous coal far from the frontier is in the Wealden beds to the east of the Weser, and it is the smallest coal-field of them all. Germany, owing to the exposed position of its coal-fields, has seen the necessity for an army capable of keeping its frontiers inviolate, as we recognise the need for an invincible navy to keep enemies off our shores.

France and Belgium also suffer from the exposed position of their coal-fields, and the worst misfortune of the war is that most of the chief coal-field of France and the Belgian coal-field fell at once into the hands of the invaders, and the tenacity with which Germany is holding them shows her appreciation of their military value.

The direction of the German-Austrian attack on Russia appears to have been influenced by the attraction of coal-fields. Fortunately for Russia her largest coal-field—that of the Donetz—is safe from invasion, but the Dombrova coal-field fell early in the war, for it stands on the western frontier, and is an extension of the German coal-field of Silesia. The German-Austrian advance along the Pripet was perhaps due mainly to the temptation of the coal mines near Kiev. These mines yield only brown coal, and are relatively small, but they maintain the chief industrial and munition producing district of south-western Russia.

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So long as coal remains the basis of modern industry Great Britain and Germany seem destined to be the two leading industrial powers in Europe. The opportunities of the other States may be gauged by their coal production in 1912 or 1913—

British Isles (1913),	292,047,544	metric tons.	
Germany (1912),	174,875,297	,,	,,
France (1912),	40,394,000	,,	,,
Russia (1913),	25,772,700	,,	,,
Belgium (1913),	22,845,310	,,	,,
	(and 2,608,640	,,	,, of briquets).

The military genius of Germany is illustrated by its occupation of the French, Belgian, and Polish coal-fields, and its hitherto successful defence of all its own.

The Mineral Oil-Fields.

The distribution of the European oil-fields has also played an important part in the strategy of the war, and may greatly exercise diplomacy at its end. The chief European oil-fields are those of the Caucasus, Rumania, Galicia, and Alsace in south-western Germany. They lie along the northern or outer side of the mountain line comprising the Alps, Carpathians, and Caucasus; and the origin of the fields is no doubt connected with the earth movements by which the Alpine mountains were elevated.

The German oil-field in Alsace is only second-rate as regards production, and after a period of rapid growth it has now begun to decline; its output, however, is sufficiently large to be very useful.

The chief Austrian oil-field is in Galicia along the northern foot of the Carpathians. The oil wells extend from Bukowina nearly to Cracow; the chief centre, Boryslav, is 40 miles south-east from Przemysl. The Russian invasion of Galicia was probably undertaken to capture the oil-fields, and their easy conquest at the beginning of the war led to the opinion that they had been permanently added to the Russian Empire. The future ownership of these oil-fields affects very conflicting interests. That Russia will recapture and retain Galicia is no doubt the earnest hope of the Scottish oil trade, for one of the characteristic features of the Galician oil is its richness in

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paraffin. If the oil-field were annexed by Russia the whole of its product would be used in the Russian Empire; the Scottish oil shale industry would thus be relieved of its most serious competitor in the supply of paraffin. This change would not, however, please industries which need cheap paraffin, and Russia, by annexation of Galicia, would increase her control of European oil production; and the change might not prove commercially advantageous to the rest of Europe.

German Copper Production.

Among the metals attention is first directed to copper, since the belief that Germany could not continue the struggle without imported copper was one of the most widespread early illusions of the war. Germany in 1913 imported 225,000 tons of copper, and the stoppage of that supply is no doubt a sound policy, as it must create a copper famine that will render some German industries economically impossible. But the hope that Germany could not obtain enough copper for ammunition appears futile. Her own production and stores should suffice. Germany in 1913 was the tenth country in order of copper production; the others in order of output were the United States, Japan, Spain and Portugal, Mexico, Australasia, Chile, Russia, Canada, and Peru. In 1913 the total copper production of Germany was about 25,000 tons, of which 20,000 came from Mansfeld, one of the most famous and interesting copper-fields in Europe.

Mansfeld is on the south-eastern border of the Harz Mountains, and its copper ore is a thin bed of shale, the "copper-slate," of which the thickness that pays to work at normal prices is usually from 3 to 5 inches (rarely 7 inches). The origin of this ore has been much disputed. According to the older theory the copper was deposited from the sea water on to the floor of the old Permian sea. The distorted shape of the fossil fish found in the bed was attributed to their having died in the agonies of copper poisoning after a sudden irruption of copper salts into the sea. The invalidity of this picturesque argument no doubt increased the popularity of the rival theory, that the ores were introduced into the rock in solution through faults and fissures, but the remarkable uniformity of this wide-

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spread ore supports the older view that the ore was deposited as a precipitate on the sea floor. It was doubtless dissolved and reprecipitated, and during this process some minor enrichments were formed around the fissures, and some copper was deposited in the adjacent beds.[1]

The question of practical importance is the possible output of the Mansfeld mines. Mining began there in 1199, and the field has yielded 750,000 tons of copper; and in spite of the fall in prices during recent years its output increased from 1500 tons in 1860, and from 14,921 metric tons in 1892 to 20,201 metric tons in 1913. This yield could no doubt be further increased. The price of copper in London varied during 1913 from £65 to £73 per ton; in 1911 the average price was only £56 a ton. At such prices the ore at Mansfeld does not pay to work, although it holds about 4 ounces of silver to the ton, unless it contains at least 2 to 3 per cent. of copper. The field, however, contains large quantities of ore with only 1½ per cent. of copper, and when copper is worth £200 a ton, as it has been in Germany during the war, this low grade ore could be used and the output of the field greatly increased. If Germany can spare the labour, Mansfeld could no doubt be so worked as at least to double its copper output, and 1000 tons of copper a week would probably suffice for the ammunition that Germany requires.

After Spain and Portugal, Russia is the greatest European producer of copper. Her copper mines are so far to the east in Perm and the Urals that they are safe from attack, and will not influence the direction of the war.

The Franco-German Iron-Field.

Iron is the most indispensable metal to modern civilisation and in warfare. Its ores are widely distributed, but one difficulty in the way of peace is that the chief iron-field of France and Germany lies along their jealously regarded frontier. This ore is known as minette, and is of nearly the same age as that of our Cleveland iron-field. The ore is of low grade, contain-

[1] The widespread adoption for a decade or two of the theory that the ore was primarily due to infiltration was due to the tendency of many mining authorities to underrate all methods of ore formation except by deep-seated, ore-bearing solutions.

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ing from 35 to 40 per cent. of iron, while there is only from 20 to 30 per cent. in the associated ferruginous limestones. The supply, however, is enormous, and it can be cheaply mined. Most of the mining field is in France, where by 1908 concessions had been granted to the extent of about 240 square miles; in addition are 45 square miles around Longwy in the northern end of the area, and some tracts where the ore has not yet been tested or lies too deep for present use. The field also includes 13 square miles in Luxembourg, 1 square mile in Belgium, and 165 square miles in the part of Lorraine which was transferred to Germany in 1871. The range of the field is shown on the sketch map, Fig. 2. The Franco-German frontier is marked by the dotted line, and it runs approximately north and south across the field.

This mining field is of the utmost importance to both Powers. The production of ore from French Lorraine has increased from 5,282,000 tons in 1903 to 8,850,000 tons in 1908, and in that year this field yielded 88 per cent. of the total iron ore production of France. By 1912 the French iron ore production had increased to 19,160,000 metric tons mainly owing to this field.[2] The French reserves of ore in this field are estimated by Nicou as 3,000,000,000 tons. The iron ore reserves in German Lorraine, excluding Luxembourg, are estimated at 2,000,000,000 tons. The total output of German iron ore has nearly doubled between 1896, when it was 14,162,325, and 1912, when it was 27,199,944 tons. The output from German Lorraine during this period increased more than fourfold, viz., from 4,841,633 tons in 1896 to 20,083,236 tons in 1912. As Luxembourg is a member of the German Customs Union its output is usually included in the German, and it has increased from 4,758,741 tons in 1896 to 7,492,870 tons in 1907. In 1896 the Lorraine field produced only about half the German output of iron ore, whereas it now yields more than two-thirds. Moreover, a steadily increasing quantity of the French ore is exported to Germany, the amount having risen to 920,000 metric tons in 1908. More than a tenth of the French Lorraine ore is now smelted in Germany, as it is

[2] The most important mining centre is Briey, which yields most of the grey ore from the Upper Lias (Toarcian).

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conveniently placed for transport to the Westphalian coal-field. Hence if the war were followed by a commercial boycott the French iron-field would lose a large customer, while Germany may be expected most strenuously to oppose any change that would deprive her of full control of the mines which furnish

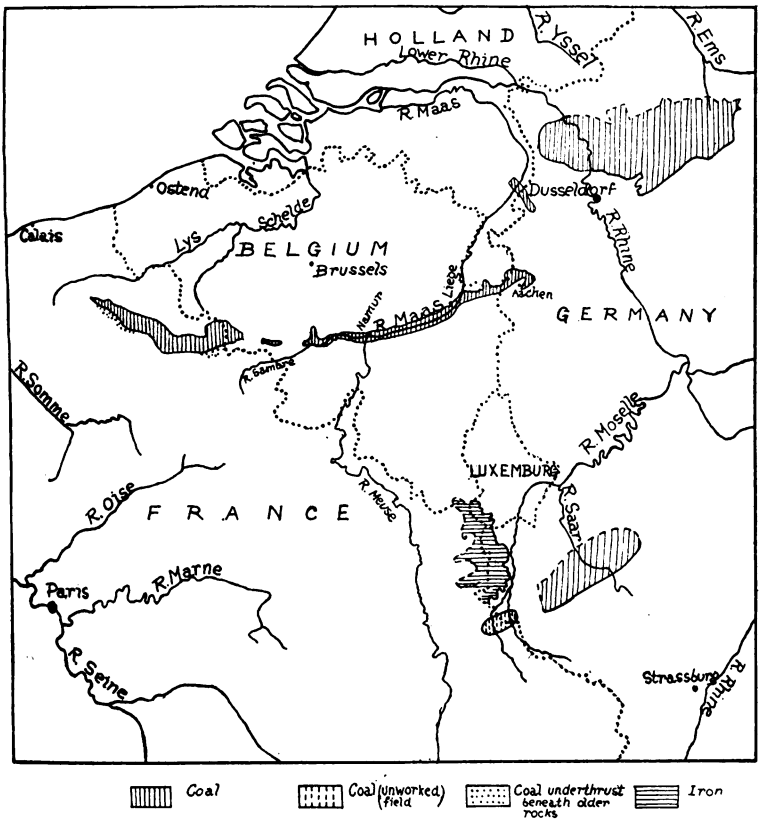

Fig. 2.—The Iron-Field of the Franco-German Frontier and the nearest Coal-Fields.

most of her iron ore. It is unfortunate that this great iron-field should lie along the Franco-German frontier, and the quantity of this unluckily placed ore is so colossal that at the present rate of working this serious obstacle to peace will not be removed by the exhaustion of the mines for at least one hundred and fifty years.

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The German Potash Monopoly.

The most interesting question of mineral distribution raised by the war is that of the potash salts, which are mainly required for fertilisers, though about one-seventh of the supply is used in the manufacture of glass, gunpowder, soap, &c. The value of potash as a fertiliser is sometimes decried, but it is one of the elements necessary for plant growth, and with some soils successful agriculture depends on its artificial renewal.

The value of potash is shown by the following facts:—A crop of wheat of 30 bushels per acre includes 9·7 lbs. of potash in the grain and 18·2 lbs. in the straw. A hay crop of 1½ tons to the acre removes from the soil 56 lbs. of potash. A 6-ton crop of potatoes uses 78 lbs. of potash. Root crops, such as turnips, require a still larger supply. There are 150 lbs. of potash in an average crop of 17 tons per acre of turnips and about 300 lbs. in a 22-ton crop of mangolds. Land which is constantly cultivated therefore requires the replenishment of its potash to avoid exhaustion.

Potash is fortunately widespread in nature, as it is an essential component of some felspars, which are the most abundant of rock constituents. It also occurs in leucite and potash mica. The main primary source of potash in soils is no doubt the potash felspars of the igneous rocks. The felspars are, however, so insoluble that their potash is not immediately available as a plant food, and it is combined with such an excess of unnutritive material that the igneous rocks are not at present an extensive commercial source of potash. The chief supply comes from deposits wherein potash was slowly concentrated during former geological periods. This beneficent process of segregation is open, in regard to the potash salts, to the charge of gross partiality, for it has collected so vast a quantity of potash in one field as to have given Germany the practical monopoly of the potash supply of the world. The inconveniences of that monopoly are manifold; among them may have been the long delay in the proclamation of cotton as contraband. Germany is said to have threatened only to send potash to the United States in exchange for cotton, and it was

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obviously not to our interest to deprive the American wheat farmers of their most important fertiliser and thus reduce our available supply of wheat.

The ultimate explanation of the German monopoly rests on the extreme solubility of potash, which prevents its deposition in large quantities except under very unusual circumstances. So far as is known the German deposits are unique. The problems connected with their origin are of great interest and difficulty. The potash no doubt came originally from the felspars, in which it occurs as an insoluble potassium silicate. As the rocks decay under the action of the weather the potash becomes soluble, and is then so soluble that there is no effective precipitant.

All river waters contain potash either in solution or suspension. The Danish rivers, for example, according to analyses by Feilberg and Westermann,[3] contain 2 to 3 lbs. of potash in each 1,000,000 lbs. of water. Rivers in flood owing to the felspathic silt in suspension contain larger quantities. Thus an Icelandic river, the Thjórsá, which usually carries down from 2 to 3 lbs. of potash in each 1,000,000 lbs. of water, was charged with 28 lbs. in the same quantity during the thaw of 1898.[4] The potash is carried by streams to the sea, and there accumulates as potassium sulphate and chloride. Seaweeds extract some of the potash, and their ash formerly yielded the chief supply of the potash salts. The formation of glauconite, the characteristic constituent of the greensands, also involves the removal of potash from sea water, and as the glauconite decomposes readily the greensands have been used directly as fertilisers. Potash is also removed from water in the soil by a complex reaction which is not yet fully understood. When lagoons or enclosed seas are evaporated their salts are deposited upon the floor. When 37 per cent. of the water has been removed the gypsum (sulphate of lime) is thrown down, and when 93 per cent. has been evaporated common salt (sodium chloride) is also precipitated. The brine left contains most of the potash salts, which are only precipitated on the complete evaporation of the water.

[3] Quoted by Thoroddsen. In the *Botany of Iceland*, pt. 1, sec. 2, 1914, p. 255.

[4] Analyses by Torfason, Detlefsen, and Meyer.

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It would therefore be expected that, on the evaporation of a body of sea water, the salts should be laid down in regular order; the least soluble salt, the gypsum, should be at the bottom, and the most soluble, the potassium and magnesium chlorides, should be at the top. The sequence is not always complete, since some geographical change may have allowed the brine containing the potash salts to escape before the evaporation was quite finished, and so gypsum and common salt often occur without potash salts. Beds of common salt occur in many lands, but potash deposits sufficiently large to be of commercial value are deplorably scarce. The most important are those of west-central Germany.

Salt deposits may be also formed by the desiccation of lakes. If rivers discharge into a lake which has no outlet the salts accumulate until they are precipitated, and the least soluble goes down first. That the salts are not all deposited at the same time is shown by the water of the Dead Sea, which is poor in lime, sulphates, and common salt.

The composition of the water in the Dead Sea, according to the oft-quoted analyses by Booth and Muckle (1849) on water collected by the Lynch Expedition[5] and to a more detailed analysis by Dr. Bernay, is as follows:—

		Bernay.	
	Per cent.	Per cent.	Grains per Gallon.[6]
Magnesium chloride, -	14·59	10·55	7388·21
Sodium ,, -	7·85	7·29	5106·00
Calcium ,, -	3·1	·85	594·46
Potassium ,, -	·66	1·58	1089·06
Calcium sulphate, - -	·07	·23	163·39
Magnesium bromide, -	·14	·49	345·80
Calcium carbonate, - -		·10	70
Magnesium nitrate, - -		·27	175·01
Iron and aluminium oxides,		·01	10·50
Organic matter; water of crystallization; loss, -		·45	317·57
	26·41	21·82	15260·00

[5] This has been reprinted with modifications by Bischof (*Chem. and Phys. Geol.*, 1854, vol. i., p. 92) and by Geikie (*Textbook of Geology*, 4th ed., 1903, vol. i., p. 529). A later series of analyses by Terreil (*C.R.*, vol. 62, 1866, pp. 1329-1332), from samples brought back by Lartet, has been reprinted by Hull (*Mem. Geol. and Geog. Arabia Petrea, Palestine*, 1889, p. 121). I owe to Dr. A. Scott reference to a still later analyses by Stutzer and Reich (*Chem. Zeit.*, vol. 31, 1907, p. 845).

[6] Quoted in Prof. Macalister's article on the Dead Sea (*Encyclopædia Britannica*, edit. 11, vol. vii., 1910, p. 879).

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The chief variations in the analyses are in the percentage of bromine, which in Terreil's series varies from ·0167 to ·7093 per cent.

The Jordan drains a limestone country, and therefore carries lime and salt to the Dead Sea; hence these salts must be precipitated as the river enters the lake. The water of the Dead Sea represents a brine from which the less soluble salts have been precipitated, and if the Dead Sea were completely evaporated the lower deposits beneath its floor would be found charged with gypsum and salt, and the uppermost series with potash and magnesium salts. The sequence would be exactly in accordance with that found in the great salt-fields of Germany.

The explanation that the German salt deposits are due to evaporation of a great inland sea is attended by several difficulties. It does not account for the enormous thickness of salt in some localities. Thus the famous bore at Sperenberg, 23 miles south of Berlin, was sunk in 1867-71 through 3878 feet of continuous rock salt in one bed without reaching the bottom of it (Fürer, 1900, pp. 108, 205). The salt in various localities occurs in masses more than 3000 feet in thickness, which, moreover, cut across the adjacent beds. Sea water contains only about 3½ per cent. of solid matter; the evaporation of 30,000 feet of sea water would only deposit a layer about 450 feet in thickness. Hence the formation of a bed of salt 3000 feet thick would require the evaporation of water about seven times as deep as the deepest of the oceans. It is clear, therefore, that these deposits cannot have been formed from an inland sea cut off on only one occasion from the ocean. The sea water must have been constantly renewed and evaporated, and the floor must have been sinking for a long period. If the supplies of sea water had been fully evaporated again and again the same sequence of salt deposits should be repeated each time. Each sequence should begin below with the comparatively insoluble sulphate of lime, and end with the potassium and magnesium chlorides. The succession is, however, very different in different localities. In some places the beds are horizontal and undisturbed, as at Eichsfeld, where the succession could be explained by a lagoon having been twice evaporated.

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The section in ascending order passes through sulphate of lime (anhydrite), rock salt, potassium salts, saliferous clay, and then follows another bed of anhydrite succeeded by rock salt. In other cases, however, the sequence is far more complex, and it is necessary to assume that surface waters have percolated downward and altered some of the original salts into various secondary salts.

Further difficulties are introduced by the occurrence of colossal domes of rock salt, on the flanks of which rest beds of other salts—as illustrated by the section across the Leopoldshall mine in the Grand Duchy of Anhalt. Such cases are inexplicable by direct precipitation from evaporating sheets of water. Various other theories have therefore been suggested. According to Walther (1908, pp. 372-3) the deposits were formed under desert conditions, the salts having been leached from older marine beds and laid down in dried-up salt lakes. Other authorities have adopted a magmatic theory, according to which the salt was deposited by ascending waters like ordinary mineral veins.

The most successful attempt to explain the thickness of the salts and the occurrence of the potash salts mainly on one horizon is the "bar theory" of Ochsenius. It can be explained by reference to the Bay of Karabugas, a basin 6640 square miles in area, on the eastern side of the Caspian Sea, with which it is connected by a narrow, shallow mouth. The water of the Caspian is fresher than ordinary sea water; but that in Karabugas is salter, for a current into the bay replaces the water lost by evaporation, and this process has concentrated salt within the basin. If the bar across the mouth were closed the water in Karabugas might be completely removed by evaporation, and all its salts precipitated on the floor; but while there is an outlet from the basin, the potassium salts can escape back into the Caspian. The floor of Karabugas is therefore being covered with repeated deposits of gypsum and common salts, but not of potassium salts. If, however, the bar were closed and the water completely evaporated a layer of potash salts would be deposited above the common salts, and the usual sequence in the German deposits would be reproduced.

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This bar theory affords a satisfactory explanation of salt deposits in such conditions as at Eichsfeld, but it does not account for such thick masses and domes as at Sperenberg or Leopoldshall.

Much light has been thrown on the origin of such salt domes and salt pillars by oil mining beside the Gulf of Mexico, in Louisiana. Some remarkably prolific wells in the Jennings oil-field near New Orleans discharge oil and gas from huge buried domes of salt, the relations of which have been determined by boring. The best known dome is at Anse la Butte, a little over 100 miles west-north-west of New Orleans, and it has been well described by G. D. Harris (1909-1910). A bore into it for oil passed through 2263 feet of almost pure salt, then through 70 feet of sediments, and ended in an unknown thickness of salt. This salt dome is 1000 feet in diameter, and its sides are so steep that a bore (Lake No. 9) 300 feet away passed through no salt (Harris, 1910, p. 37). This dome is surrounded by beds of clay and sand, which for a distance of 500 feet are greatly disturbed and uptilted. Harris' section through this dome shows the abruptness of the margin, the disturbance of the adjacent beds, which dip in all directions from the dome, and the occurrence of projecting shelves or tongues of salt. The oil well at Sour Lake, according to Harris' section, is especially instructive; the oil comes from a buried pillar of salt, which is unquestionably a secondary formation, as it has been formed near the top of a fault which traverses the underlying Kainozoic and Cretaceous rocks, and probably continues downward into saliferous Triassic or Permian deposits. If this section be correct, the salt dome must be a secondary formation and due to ascending solutions.

There are at least fifty salt domes in this oil-field, and their distribution is instructive. They are arranged on a rectangular plan, which is explained by their occurrence at the points of intersection of the two fault systems of the district. These Louisianan salt domes cannot be explained by the evaporation of inland seas or lakes. The geologists who have studied them have all felt bound to appeal to other processes. Thus Dr. R. T. Hill (1903, p. 397) ascribes them to ascending salt solutions, which have risen through "planes of structural

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weakness" and have soaked through and replaced blocks of fissured rock. Hager and Veatch, on the other hand, explain the salt domes as masses of salt which have been thrust upward into overlying softer sediments by an underlying laccolite of intrusive rocks; but the absence of any evidence of these igneous rocks or of any characteristic igneous minerals, and the presence of horizontal tongues of salt which project from the salt mass into the other sediments are serious objections to this explanation.

G. D. Harris has introduced a variety of the lateral secretion hypothesis. He regards the salt as having been leached out of the underlying Palæozoic and Mesozoic rocks by ascending water, which deposits it as a mass; fresh layers are added to the base of the mass, and their crystallisation thrusts it upwards, like a wedge, into the overlying sediments. Harris has illustrated his theory, which seems the most probable, by a series of diagrams published in "Economic Geology" (vol. iv., 1909, p. 24). They show the gradual formation of a block of salt around a fault, and its intrusion into the sediments above it. The projecting tongues of salt are due to secondary redeposition on the sides of the mass.

Deposits of rock salts have therefore two modes of origin. Where the salt measures are widespread regular beds, and the salt occurs in groups of lenses, as is shown in Hay's section across central Kansas (Hay, 1891, Fig. 3), the salt was doubtless due to deposition in lake basins or salt pans. When the salts are deposited in widespread sheets which overlie marine beds, and occur in the regular sequence of solubility, as in the Eichsfeld district of Germany, they were doubtless due to deposition from a dried-up sea.

High pillars of salt and vast salt domes are not satisfactorily explained as primary deposits, and the mineralogical sequence and arrangement of the salts in some localities give conclusive evidence of the secondary origin of much of the German potash salts. The salts which form the mainstay of the potash industry are, in fact, secondary deposits.

The formation of great salt domes by secondary redeposition is probable where salt-bearing beds have been disturbed by

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German Frontier
Shores of Zechstein Sea
Older lands which in Germany break the continuity of the Salt Deposits
Bohemian Basin (Cretaceous)
St. Stassfurt
K. Cologne
M. Magdeburg

Fig. 3.—The distribution of the German Salt Fields.

× Indicates Potash Mines.

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earth movements. Thus the salt mines in the Maros valley in Hungary work a block of salt which is of Kainozoic age, as it overlies the Leithakalk. Lamprecht (see Fürer, 1900, pp. 262-266) explained this salt dome as an anticlinal fold in a bed of salt. But, as Harris has pointed out, this explanation does not agree with the facts shown in Lamprecht's section across the mines; and the Maros salt block was probably formed by redeposition of salt leached out of adjacent salt beds.

Another huge salt dome occurs in Algeria, at Rhang-al-Melah, 14 miles north-west of Jelfa. It is bounded partly by Cretaceous and partly by Kainozoic rocks. The beds dip away from it, and are in places inverted. On the upper edge is an angular breccia of siliceous rocks, and threads ("filets") of copper and iron pyrites occur in the Cretaceous marls beside it (Ville, 1859, p. 375). It was investigated by Ville in 1855. He described the salt beds of the adjacent localities as deposited from the sea, but this block as intrusive. Ville concluded that "Tous ces faits donnent lieu de penser que le gîte du rocher de sel est le résultat d'une éruption boueuse et saline qui s'est opérée à travers les assises superposées des terrains crétacé inférieur et tertiaire moyen."

The volcanic origin of some salt deposits has also been supported by Dr. G. E. Pilgrim, of the Indian Geological Survey. In 1908 he maintained that the salt at Kamarij, near the Persian Gulf, is of volcanic origin, and is due to a saline injection of a subterranean magma containing chloride of sodium.

Returning now to the German salt-field, and considering it as a whole, as shown in the diagrammatic section, Plate I., Fig. 2, after Everding, the deposits are generally widespread, regular beds. The domes and pillars are exceptional occurrences in disturbed localities (Plate I., Fig. 1). The salt beds are regularly interstratified in the Upper Permian, a little below the Lower Trias. They belong to a sequence which began with the ordinary marine beds of the Permian Sea, lasted through the destruction of the marine fauna owing to change in the composition of the sea water, and ended with extensive desert deposits. The salt beds were laid down at a date when the evaporation of a great inland sea was a very probable event.

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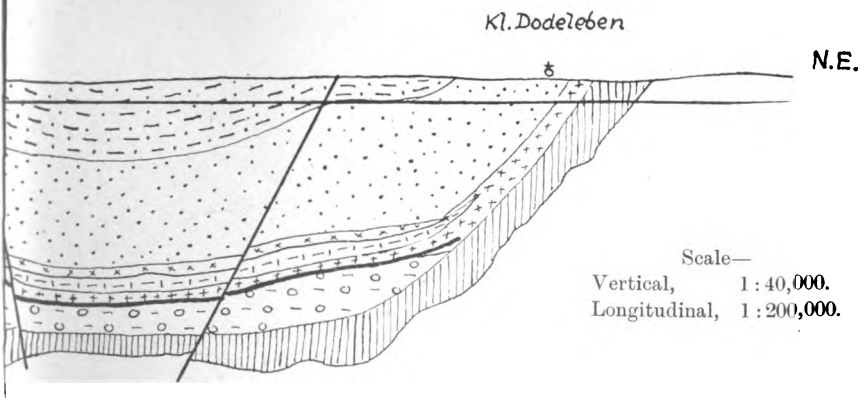

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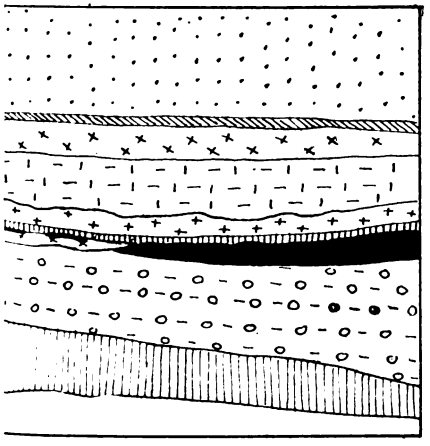

: Werra Type
: Hanover Type
: S. Harz Type
: Stassfurt Type

man Salt Fields, showing the general
nplified from a section by Everding.)

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The salt beds occur in two divisions, and the chief potash deposits are at the top of the lower (Plate I., Fig. 2). The sequence of the salts begins with an older salt bed, of an average thickness of about 1000 feet. It is composed of alternate layers of rock salt and gypsum, which are repeated so often and with such regularity as to suggest a series of seasonal deposits like the rings of growth in a tree.

The older rock salt ends with a widespread layer of potassium salts, which are covered by a thin protective layer of clay.

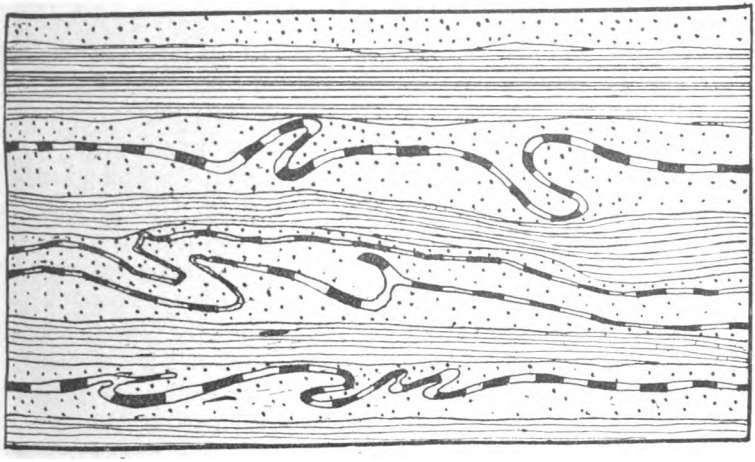

Fig. 4.—Section in the Salt Deposits near Stassfurt, showing the contorted layers of Kieserite in Carnallitite and interbedded with horizontal beds of Rock Salt. Scale, 1/24. (After Everding.)

Then follows another great deposit of sulphate of lime (anhydrite), above which is the younger rock salt series, and this is succeeded by the last of the Permian sediments and the Lower Triassic sandstones. The sequence of the salt deposits is explained by Ochsenius' bar theory. During the deposition of the lower rock salt the sea must have been connected with the main ocean, so that the supplies of salt and sulphate of lime were continually renewed, while the more soluble potash and magnesian salts were removed by a return current. Then the outlet was closed, the whole of the water was evaporated, and the potash salts precipitated. After some interval the ground

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sank again, the area was reflooded by the sea, and the deposition of rock salt and sulphate of lime was renewed. During this period some potash salts were occasionally deposited, but at its end the residual brine escaped to sea, and there was no final layer of potash deposits. Then in Kainozoic times the beds of the salt area were folded, faulted, and sometimes inverted by the disturbances connected with the formation of the Alps. Then were formed the overthrust faults on the northern margin of the Harz, the folds of Stassfurt and Egeln, and the innumerable faults which add so much to the difficulty and danger of the salt mining (Plate I., Fig 1).

A general survey of the whole area is then in favour of the origin of the German salts by deposition from a dried-up sea, but closer attention to details shows that this simple explanation is incomplete. In addition to the primary deposits thus caused, there are important secondary deposits. The primary potash deposits include successive layers (Fig. 4) of carnallite, rock salt, and kieserite.[7] All three minerals in such a section were doubtless deposited directly from evaporating sea water. In an adjacent locality (Fig. 5), where the beds have been tilted steeply, the carnallite and kieserite end abruptly beneath a cap of kainite, through which the layers of rock salt are continued unchanged. As Everding has shown, such sections prove that the kainite has been formed by the alteration of carnallite after the beds were tilted. Hence the kainite is a comparatively modern formation. The recent origin of the kainite is also shown by a section from Westeregeln. Here the potash salt is

[7] The chief minerals in these salt deposits are as follow:—

Simple Minerals—

Carnallite, - -	$KCl, MgCl_2, 6H_2O$.
Kainite, - - -	$KCl, MgSO_4, 3H_2O$.
Kieserite, - -	$MgSO_4, H_2O$.
Langbeinite, - -	$K_2SO_4, 2MgSO_4$.
Rock Salt (Halite),	$NaCl$.
Polyhalite, - -	$2CaSO_4, MgSO_4, K_2SO_4, 2H_2O$.
Sylvine, - - -	KCl.

Compound Minerals—

Carnallitite, - -	$KCl, MgCl_2, 6H_2O + xNaCl$.
Hartsalz, - -	$KCl + xNaCl + yMgSO_4, H_2O$.
Hauptsalz, - -	$KCl, MgCl_2, 6H_2O, + xNaCl, + yMgSO_4, H_2O$.
Kainitite, - -	$KCl, MgSO_4 3H_2O + xNaCl$.
Sylvinite, - -	$KCl + xNaCl$.

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interstratified between the salt clay and the lowest rock salt, and it is crowned by a cap of secondary kainite.

Much of the sylvine (KCl) is certainly of secondary origin. Thus in the Ronnenberg mine (Fig. 6) the potash salts occur in a vertical series of veins between two thick sheets of rock salt. The potash veins have been distorted, and the beds have been dislocated by inclined faults. Some of the sylvinite veins occur along the faults, showing that they were formed

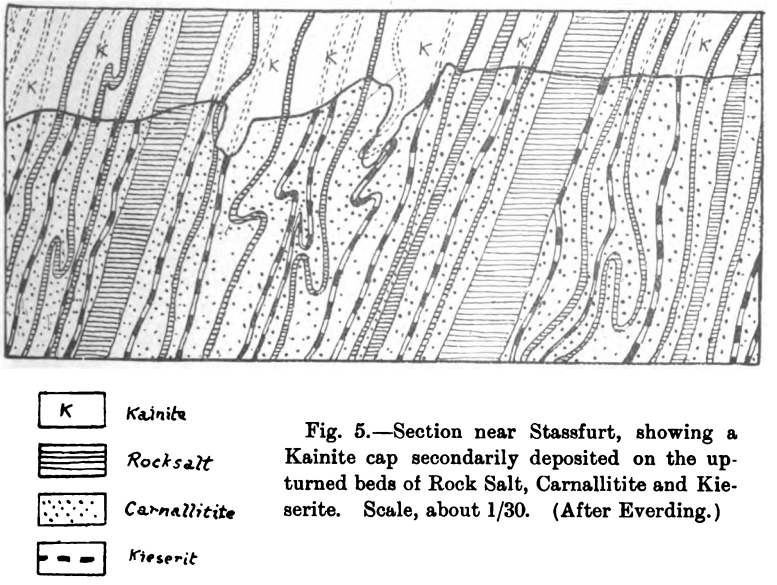

Fig. 5.—Section near Stassfurt, showing a Kainite cap secondarily deposited on the upturned beds of Rock Salt, Carnallitite and Kieserite. Scale, about 1/30. (After Everding.)

after the faulting. A section at the Deutschland mine, near Weetzen, shows the same fact in a somewhat simpler case. The "Hartsalz," or hard salt (a mixture of sylvine, rock salt, and kieserite) occurs as a vein between rock salt and anhydrite. The anhydrite is cut through by faults which do not dislocate the "hard salt," which is therefore later than the faulting.

The salt deposits have, moreover, often undergone extensive solution; thus a photograph by Everding from the Deutschland mine shows disturbed and dislocated rock salt covered by residual beds of the insoluble gypsum.

Everding classifies the salts into three generations. The

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first, the primary deposits, which he calls the "mother formation," includes those which were deposited directly from the evaporating waters. The second group, the secondary salts, the "descendenz" salts, were formed shortly after the first group by water working through the unconsolidated beds and dissolving salt at one point and depositing it at another. The

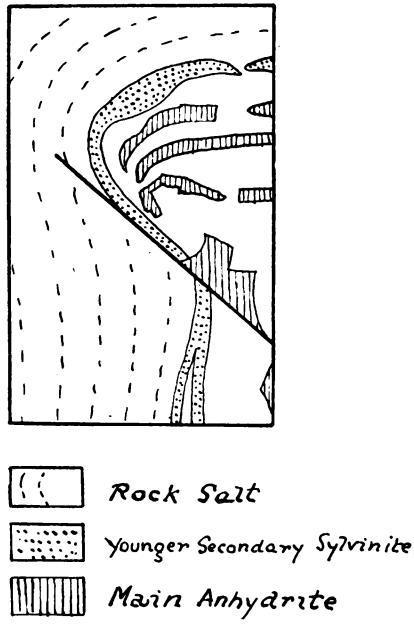

Fig. 6.—Section in the Ronnenberg Mine, showing the Formation of the Sylvinite after a series of transverse faults. Scale, 1/1000. (Enlarged and simplified from a section by Everding.)

third group, the later secondary salts, which Everding calls the "posthumous formations," were formed after Permian times. They include the kainite caps and the veins of sylvinite and hartsalz, which are later than the faulting. Members of all three generations are shown together in Fig. 7 from the Hercynia mine, near Vienenburg. The older rock salt to the left and the anhydrite bed in the middle are both primary or "mother formations." Between them are three layers, a conglomerate of "Hauptsalz" or chief salt (a mixture of

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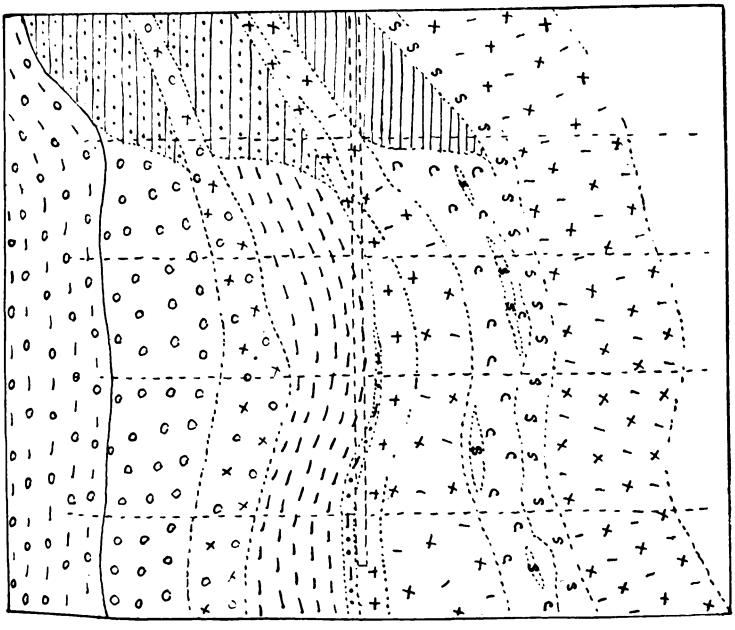

Sylvinite Cap

Kainite Cap

Younger Secondary Sylvinite

Carnallitite, secondary; derived from Sylvinite

Main Anhydrite

Saliferous Clay

Secondary Bedded Hauptsalz

Secondary Hauptsalt Conglomerate

Younger Secondary Rocksalt

Older Secondary Rocksalt

Older Primary Rocksalt

Fig. 7.—Section in the Hercynia Mine near Vienenburg showing Kainite and Sylvinite Caps on beds of Hauptsalz and Carnallitite. Scale, about 1/2700. (After Everding.)

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carnallite, rock salt, and kieserite), a bed of rock salt, and a bed of hauptsalz. They are all three secondary, and were deposited during the consolidation of the deposits. A bed of sylvinite still higher in the series also belongs to the earlier secondary division. The post-Permian formations include a kainite cap above the hauptsalz, and a sylvinite cap above a bed of carnallite that has been formed from sylvinite.

The German salt minerals therefore include (1) primary deposits formed by direct deposition from the Permian Sea; (2) earlier secondary salts due to redeposition during the consolidation of the Permian deposits; and (3) later secondary salts formed after the Kainozoic earth movements.

There is no evidence that any of these salts are of magmatic origin. The constituents of the characteristic accessory minerals found in them, the bromides and iodides, are found in sea water, while the typical magmatic materials, boric and fluoric acids, are exceptional. Some boric minerals, such as boracite, do occur, but they are local, and their presence is not surprising since the region was the scene of intense volcanic activity shortly before the existence of the inland seas. The general section across the area shows that the salt deposits as a whole are regularly interstratified in the Permian and Triassic succession. The perplexing features are due to secondary rearrangements.

Hence in the old controversy between the Plutonists and Neptunists as to the origin of the salt deposits the truth was divided between the two camps. The Plutonists were right in holding that many of the potash salts were secondary deposits due to solutions working their way along fissures, fractures, and permeable beds. The Plutonists were wrong in their unnecessary appeal to a deep-seated source for the materials, but they truly recognised that the simple Neptunist theory was inconsistent with many facts, which its supporters quietly ignored, and that some of the salt deposits of the greatest commercial importance were formed after the deposition of the rocks by infiltering solutions.

The political importance of this salt question depends on the fact that the maintenance of the German potash monopoly

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depends on the continuance of the present Franco-German frontier. The geological history of the German salt deposits shows that they are the result of such exceptional geographical conditions that it is not surprising that the world has been ransacked in vain for an alternative supply of potash. The search has been stimulated by the restriction in Germany on the potash output. At one time there was an outcry against the export to rival agricultural countries of fertilisers, which it was said would be required later on by German farmers. The Government commissioned Ochsenius, one of the most competent authorities, to report on the extent of the supply. He estimated that between Berlin, Segeberg (north-north-east of Hamburg), Halberstadt, and the Weser the deposits extend through 24,281 square miles, and contain 143,360,000 tons of salt per square mile, so that with the consumption of 5,000,000 tons per annum the supply from that one area would last over six hundred thousand years. The deposits will outlast the German Empire and most other Empires too. The output is not restricted for fear of exhaustion. The German Government claims that as these minerals are national property the State has the right to a fair share of their value, and should see that each of the mining districts has a fair chance. Hence it prevents ruinous competition which might abolish profits and stop mining in the districts which are most expensive to work. The Government also restricts mining concessions in order to protect the public water supply. The waste waters from the salt works pass into the rivers, which might be ruined if the industry were uncontrolled. The rivers of the Magdeburg district were at one time thus rendered non-potable, and the local output is now regulated so that the amount of salt in the rivers is kept below a safe limit.

The American potash merchants have, however, made determined efforts to evade the restrictions. As no new concession could be obtained, the Virginia Carolina Company in 1905 purchased a German salt mine, but the regulations of the Kali-Syndicat prevented any increase in the output. In 1909 the Syndicate agreement had to be renewed, and as no settlement was reached it lapsed at midnight on the 30th June. During the next two hours the American Agricultural Corporation pur-

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chased the Sollstedt mine, and made long contracts for increased supplies from other mines. On hearing of these proceedings the chairman of the Syndicate immediately resummoned the conference, which met at 9 a.m., and a new agreement was then adopted. The contracts made in the interval could not, however, be legally cancelled. It was proposed therefore to neutralise them by an export tax. This step would have been of doubtful legality, and it was proposed in America to retaliate by a 25 per cent. tax on all German imports. So instead the Reichstag in 1910 passed the potash law, which compelled all the mines to join the Kali-Syndicat, restricted the output of each mine to a definite percentage of the total, and fixed prices to 1913 and output to 1925. This measure counteracted the smart midnight contracts of the American Corporation, which agreed to cancel them in exchange for permission to raise an additional 20,000 tons per annum from the Sollstedt mine.

The American merchants, thus foiled, have renewed the search for an independent supply of potash, and the war has also directed attention to many of the old sources. Small quantities of potash are obtained in various parts of the world by men in their odd time and as by-products. Thus kelp, or seaweed ash, has long been prepared on the coasts of Scotland, Ireland, and Norway, and efforts are being made in the United States to manufacture it on a large scale from the richer Pacific seaweeds. But as even they yield only 15 per cent. of dried kelp, which contains 15 per cent. of potash salts, 44 tons of seaweed yield only 1 ton of potash salts. Hence the kelp industry will have to be very economically conducted to be a commercial success.

Some potash is obtained from wood ashes. About 6000 tons a year are yielded in the Caucasus from the stalks of the sunflowers which are grown for oil. Some is extracted from wool grease. From 1000 to 2000 tons of potassium chloride are derived annually as a by-product from the salt pans of southern France and Spain. Many lakes in arid districts collect potash which is leached in some places from the adjacent rocks, as in the Lonar Lake in India,[8] and in others from the

[8] La Touche. The Geology of the Lonar Lake. With a Note on the Lonar Soda-Deposit, by W. A. K. Christie. *Rec. Geol. Surv. India*, vol. xli., pt. 4, 1912, pp. 266-85.

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ashes of prairie fires, as in Jesse Lake in western America. India yields from 10,000 to 20,000 tons a year of nitre of organic origin. The minerals alunite and glauconite, which contain from 3½ to 6½ per cent. of potash, are used for local supplies.

The mines at Kalusz, in Austria, yielded about 2000 tons a year from 1904 to 1908, an amount which before the war it was hoped to increase greatly. The output is all compulsorily sold to the Austrian Government, so Kalusz cannot be expected to help foreign consumers. The best hopes of a large non-German supply in Europe rest on the seams of potash salts recently discovered in the long-known salt deposits at Cardona, in Catalonia. The rock salt there is so massive that its outcrops have been described as resembling glaciers. The reports published last year on the efforts to develop this Spanish deposit suggest that it may become an important contributor to the potash market, but its capabilities are still unproved.

The extraction of potash directly from igneous rocks is being strenuously attempted in many countries, and numerous processes[9] have been patented. Efforts are being made to use leucite lavas in Italy, and dykes rich in potash felspar in the eastern States of America. The rocks of the Leucite Hills of Wyoming are estimated to contain 10·7 per cent., or a total of 200,000,000 tons of potash. A scheme was advanced in 1912 to treat 50,000 tons a year of an Icelandic lava at Hafno Fiord, near Rekjavik. In some special circumstances potassic rocks may be used successfully; thus a fertiliser free from sodium chloride and claimed as especially suitable for vines, tobacco, and potatoes, is prepared from German phonolite. It is, however, very doubtful whether ordinary fertilisers can be profitably made from igneous rocks unless some use can be made of the residues. To mine a hard rock and extract by electric smelting or chemical treatment its 10 to 15 per cent. of potash is not a promising proposition while kainite is raised in Germany for 7s. a ton.

In America the natural concentrations in the western lake deposits justify careful prospecting, for some of the closed lake

[9] See, *e.g.*, Cushman and Hubbard. *Journ. Amer. Chem. Soc.*, vol. xxx., 1908, p. 779.

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basins receive the drainage of large areas of rocks rich in potash. Two hundred lake beds have been tested. The most promising is Searles Lake, in California, which has been long worked for borates. The lake deposits are 12 square miles in area, are 75 feet thick, and are saturated with brine. The composition of its dried residue is as follows:—

Sodium chloride, - - - -	51·61 per cent.
Sodium sulphate, - - - -	19·22 ,,
Sodium carbonate, - - - -	12·79 ,,
Sodium diborate, - - - -	3·23 ,,
Sodium arsenate, - - - -	0·17 ,,
Potassium chloride, - - - -	12·07 ,,

The quantity of potassium chloride available is estimated at 24,000,000 tons. Works have been constructed to pump and treat daily 2,000,000 gallons of the brine. The extraction of the potash involves the separation of the boric acid, and the amount obtained will be far in excess of the world's consumption. The commercial success of Searles Lake will depend on the discovery of further uses for boric acid. Some American authorities are sceptical of success, owing to the cost of transport to the central and eastern States, where the fertilisers are required.

In spite, therefore, of the vigour with which the world has been hunted for non-German potash it is doubtful whether there is any supply which can compete with the German mines, except for special and local uses or when worked as a by-product. Upper Alsace, however, contains well-proved potash deposits which, if that province were restored to France, could yield a far greater supply than they do now. The deposits were discovered in 1904 during a search for oil. A bore at Wittelsheim, 6 miles north-west of Mulhausen, failed to obtain oil, but reached rock salt at the depth of 1175 feet, and revealed two beds of potash, one at 2057 feet and a second at 2129 feet.

The chief potash mineral present is sylvinite, a mixture of the simple minerals sylvine (KCl) and rock salt. The deposits are much younger than the salt beds of central Germany, and they were formed by the evaporation of an arm of the Oligocene sea, which covered parts of south-western Germany. An extension of the deposits across the Rhine into Baden has also been proved. The lower bed in Upper Alsace has an area of

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67 square miles, and a mean thickness of 11·53 feet, and contains 84½ per cent. of sylvinite. The upper layer has an area of 33 square miles and a mean thickness of 3·8 feet. The "Gewerkschaft Amelie" was instituted in 1906 to investigate and work the deposits. It has made 120 borings, and proved the occurrence of the potash throughout an area of 78 square miles to the north and north-west of Mulhausen. Shaft sinking began in 1908, and the output of potash in 1910. In 1911 68,000 metric tons were raised, and in 1913 twelve mines were working, and the output was 350,000 metric tons.

The total quantity of potash minerals is estimated at 1,142,000,000 tons, containing 300,000,000 tons of pure potash. The gross value of the deposit is estimated at over 50 milliards of marks. This field is at present only allowed to produce 4 per cent. of the German total. If it were independent of the Kali-Syndicat it could be so worked as to yield a quantity equal to the total German export, but as this competition would seriously disorganise the German potash industry, Germany will resist the loss of Alsace for commercial as well as for sentimental and military reasons. And unless Upper Alsace be restored to France or be granted commercial autonomy the German potash monopoly will doubtless be re-established after peace.

It has been frequently suggested that if, at the end of the war, the Allies are in a position to demand a heavy indemnity, the potash mines might be held as security. The mines, however, are so scattered that to hold them would mean the occupation of areas in west-central Germany ranging from Hanover to Bavaria and from Berlin to the Rhine, and as the total value of the output in 1912 was not much over £10,000,000, the profits would be too insignificant to count in war finance. The scheme might suit the foreign potash merchants, but it would be a very unprofitable business for those who had to hold the potash-fields.

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No. II.—On Primary Analcite and Analcitization. By Alexander Scott, M.A., D.Sc.

[Read 11th November, 1915. Issued separately, 28th November, 1916.]

Although in recent years a large number of rocks containing analcite have been described, there is still some difference of opinion regarding the origin of the mineral. It had often been observed in igneous rocks, but was always considered to be secondary until, in 1890, Lindgren (*cf.* 1893, p. 289) concluded that it must be primary in some analcite-basalts. These rocks contained phenocrysts of olivine, augite and analcite in a mesostasis of the two latter minerals. The analcite was separated and analyzed and the composition found to agree with $NaAlSi_2O_6.H_2O$. In the same year, Hunter and Rosenbusch (1890, p. 455) determined the chemical composition of the "glassy" base of the monchiquites, but Pirsson (1896, pp. 682-3) was the first to identify it as analcite. He considered the mineral in this rock to be primary, as also did Cross (1897, p. 690) in a phonolite, Washington (1898, p. 187) in a tinguaite, and Coleman (1899, p. 436) in heronite. This view, to which most of the British writers who have recently described analcite-bearing rocks have subscribed (*cf.* Campbell and Stenhouse, 1908, p. 128, and Flett, 1910, pp. 295-6), has been upheld particularly by Tyrrell (1912, p. 71) in the case of the Permo-Carboniferous rocks of the West of Scotland.

Hibsch (1910, p. 427) is of the same opinion with regard to the mineral in nephelite-basalt and monchiquite from Bohemia. Most of the continental writers, however, postulate a secondary origin. Thus Brögger (1890, pp. 223-32) and Ussing (1894, pp. 118, 135) considered it to be derived from nephelite or sodalite, while Freudenberg (1906) and Rosenbusch (1908) took the former as the original mineral. Brögger has described in detail nephelite pseudomorphed by sodalite, thomsonite and analcite, but these observations are not capable of extension to other cases. The secondary minerals are not, strictly speaking, pseudomorphs, as they occur in aggregates in cavities and their derivation from original nephelite is not certain. Mohl (1875, p. 699), Rohrbach (1886, pp. 31-3) and others favour felspar as the parent mineral,

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and the basis of their chief argument is the fact that felspars are often found partly or totally replaced by analcite or some other zeolite. Similarly the replacement of nephelite by analcite is adduced by Freudenberg as evidence of the derivation of the latter from the former.

Thugutt (1912), again, considers that the mineral arises from the alteration of leucite. The two salts are analogous in composition—the water in the analcite does not seem to form an essential part of the molecule—as they give the same ammonium derivative (Clarke and Steiger, 1902, p. 17) and, as has been demonstrated synthetically by Lemberg (1876) and Thugutt (1895), each may be transformed into the other by the action of sodium or potassium salts as the case may be. Thugutt criticises destructively the idea of primary analcite (1912, p. 111) and ascribes the analcitization of nephelite to a reaction between a magmatic residuum of leucitic composition,—"*la pâte rocheuse riche en leucite,*"—and the already formed felspar, the leucite being later altered to analcite by the agency of percolating solutions. The comparative rarity of leucite is explained by the great tendency it exhibits for decomposition and alteration.

In general the chief arguments against the primary nature of analcite have been the difficulty in admitting the presence of sufficient water in the magma, the freshness of the mineral compared with the altered condition of the nephelite, felspars, &c., which may be associated with it, the replacement of these minerals by it and its occurrence as an obviously secondary mineral in veins and geodes in lavas. Although it had generally been considered that magmas held water in solution and that this water played a large part in volcanic activity, the observations of Brun (1911 and earlier papers) converted many people to the opposite view. Brun maintained that, at the time of eruption, lavas were either anhydrous, or hydrated by water from external sources, a view which has been held by some petrologists to be tantamount to a denial of the existence of magmatic water in appreciable quantities (*Cf.* Thugutt, 1912, p. 111). These results have been criticised by Day and Shepherd (1913), who have pointed out the inadequacy of the hygrometric and condensation methods which were used by Brun. A further series of observations and analyses,

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by the latter authors, of the lavas of Kilauea and their gaseous emanations, shows that water is an essential constituent of the liquid lava and that it is very probably "magmatic in character and an original constituent of the magma" (1913, p. 603), thus verifying the earlier statements of Gautier (1906) and Chamberlin (1908). From the physical-chemical point of view, there seems to be no valid reason why molten silicates under pressure should not dissolve water and other gases, although at the same time, it is essential to remember that it is practically impossible for these gases to be in equilibrium at the time of consolidation of the rock, owing to reactions which ensue on the release of pressure. While the data, so far, are purely qualitative, they seem to dispose of the first of the above objections to the existence of primary analcite. Indeed the fluidity of many alkali rock-magmas is probably to be explained by the presence of dissolved gases.

The second and third objections may be considered together, as the altered condition of the minerals of earlier formation represents the initial stages of the process which culminates in their complete replacement by analcite. The replacement of nephelite and felspar by analcite, which has been termed analcitization by Flett, is a process akin to the albitization of Bailey and Grabham (1909). Two types of analcitization can be recognised; one which occurs during the cooling of the rock and is more or less simultaneous with the consolidation of the analcite in the groundmass, and another, which occurs at a later stage after the consolidation of the rock. In the latter case, which has been described by Smellie (1916, p. 361), felspar is not easily attacked but ferromagnesian minerals are. Olivine is completely replaced, while the felspars only "show small patches and ribbons of analcite." The pyroxene has been partly recrystallized as green prismatic crystals of ægirine-augite. The well-developed form suggests that the crystals formed under conditions of low viscosity. The corrosion was probably effected by the action of solutions of alkaline silicates in water and hence is strictly comparable with pneumatolytic phenomena. It must have occurred after the consolidation of the rock and was probably analogous to the serpentinisation which is sometimes found in acid rocks, such as the soda-rich felsites of the West Renfrewshire hills.

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The first kind of analcitization, however, takes place at an earlier stage in the cooling-history of the rock and is due to the action of an alkali-rich magmatic residuum on the already-formed phenocrysts. Of the minerals which occur in analcite-bearing rocks, the felspars and nephelite show the greatest tendency to undergo analcitization. The alteration of the felspar begins round the margin of the crystals and along cracks and cleavage lines. Crystals often show undoubted signs of magmatic corrosion so that the boundary may disappear and the crystals, in ordinary light, seem to merge into the groundmass (*Cf.* Tyrrell, 1915, p. 308). In some cases, embayments of analcite may be found in the felspars while occasionally whole crystals are found replaced. Where the replacement commences along cleavages or cracks, "islands" of unaltered felspar may occur in the midst of analcitized material, and irregular patches of the latter may be found in the former. Sometimes the alteration proceeds along twinning planes. The analcitized portions are usually dusty in ordinary light and the analcite rarely shows optical anomalies. So far as can be ascertained, the original nature of the felspar exerts little influence on the process, and it is difficult to say whether one type is more liable to alteration than another. Acid labradorite seems to alter more readily than the more basic types, but even this is doubtful. The amount of alteration, however, seems to vary with the amount of analcite in the rocks, as it is the types which contain most analcite which show the greatest amount of analcitization. Occasionally other zeolites, such as thomsonite and natrolite, are found replacing felspars, but the controlling factor is probably the composition of the corrosive solution and not that of the felspar. In these respects the process differs from albitization, where the basic plagioclases are more readily attacked. The replacement of nephelite is similar. Some experimental work on hydrothermal syntheses throws some light on this reaction. Doelter (1890, p. 133) has prepared analcite by the action of soda solutions on nephelite at 200°, but he found it impossible to obtain natrolite from the latter under any conditions. Lemberg (1887, p. 567) obtained analcite in a similar fashion from oligoclase and andesine, and found that the rate of reaction increased with the silica-content. Though these reactions in the laboratory differ from those in nature in the much greater

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amounts of water and the lower pressures, it is probable that the alteration of the felspars and nephelite in the rocks proceeds in a very similar fashion.[1]

The replacement of felspar by analcite has been noted by numerous British authors and, in the case of continental rocks, particularly by Hibsch (1910, p. 427) and Stieglitz (1911, p. 385). Analcitization of felspar occurs fairly commonly in the Scottish Carboniferous rocks and is almost universal among the Permo-Carboniferous rocks of Ayrshire. The Tertiary analcite-rocks in Arran show similar phenomena, but to a much smaller degree, as is to be expected, since the crinanites contain less analcite than the late Palæozoic alkaline rocks of the mainland.

In some cases, ferromagnesian minerals have undergone similar alterations, but the resulting product is not analcite but water and alkali-bearing ferromagnesian minerals. In the essexites of Crawfordjohn (Scott, 1915, p. 457) and Ayrshire the olivine crystals are often surrounded by rims of biotite or chlorite, particularly where in contact with analcite. The biotite, which is intensely pleochroic and may be a soda-bearing variety, seems to be formed by the corrosion of the olivine by an analcitic magma, the products of the reaction crystallizing as mica. Sporadic flakes which occur in the ground-mass of the Crawfordjohn rock probably arise in the same way. A similar development of mica also occurs round the crystals of titanmagnetite in these essexites, the spaces between the secondary axes of the skeletons being often occupied by the mineral. Pyroxenes are also liable to alteration, the corrosion product being sometimes a soda-rich augite and, rarely, a mica.

Pyroxenes and amphiboles, however, often show a phenomenon which, though not the same as the above-described alterations, is indicative of the progressive enrichment of the magma in soda during consolidation. During the course of crystallization of these minerals the content of soda-bearing molecules in the liquid increases, and consequently the early-formed crystals are surrounded by a rim of soda-rich pyroxene or amphibole, as the case may be. In the case of the basic alkali-rocks, the pyroxene is usually a deep

[1] It is interesting to note that Thugutt (1895, p. 604) found that while the reaction between leucite and analcite is reversible, the reaction between felspar and analcite is irreversible.

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purple titanaugite, which has often an outer zone deeper in colour and free from inclusions. This is distinct from the finely-banded zoning which is generally present, and this outer rim seems to differ in composition from the rest of the crystal, as the optical properties are somewhat different. In the Ayrshire rocks, the purple augite has sometimes a periphery of green ægirine, indicating a much greater content of alkali (Tyrrell, 1915, p. 307). Pelikan (1906, p. 114) describes crystals of ægirine-augite surrounded by a zone of ægirine, while Cornu (1911, pp. 71, 83) found in some analcite-bearing rocks grey-violet augite with green rims, and a second generation of green pyroxene microlites. Similarly the amphiboles, as in the Howford Bridge rocks, sometimes have a soda-rich margin.

Thus, there are three ways in which rocks may be modified by the action of material of alkaline composition. Firstly, during the crystallization of the earlier minerals the liquid residuum becomes enriched in sodium and the later molecules which attach themselves to the pyroxenes and amphiboles are richer in this element than the earlier ones. Secondly, the already-formed phenocrysts may be corroded by the analcitic magma, with, in the case of the ferromagnesian minerals, the formation of biotite, at a period anterior to the consolidation of the analcite, but posterior to the formation of the other minerals, and with the analcitization of the felspars and nephelite. Thirdly, the rock, at some period subsequent to consolidation, may be acted on by waters containing silicates approximating to analcite in composition, and various minerals replaced by the zeolite with the recrystallization of the ferromagnesian material as soda-pyroxene. The first of these occurs at fairly high temperatures and at an early stage in the cooling history and the second at a late stage in the cooling history, while the third is a juvenile reaction. The cooling history of such a rock as an essexite or a theralite may be shortly summarised thus. Firstly, the formation of the olivine, pyroxene, and porphyritic felspar takes place, then the later felspar and nephelite, followed by the corrosion of the ferromagnesian minerals and the recrystallization of the dissolved material as ægirine and biotite, and finally the analcitization of the felspar and the crystallization of the residual analcite. In the case of albitization, Bailey and Grabham postulate the presence of

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carbon dioxide, and assume that the process is the result of "stewing in a solution of sodium carbonate." In the case of analcitization the presence of carbon dioxide does not seem to be necessary, particularly as Lemberg found that if solutions containing sodium carbonate, chloride or sulphate reacted on minerals such as felspars, the resulting product tended to contain these acid radicles, while sodium silicate alone gave analcite. Thus it is obvious that the analcitized and otherwise altered condition of the minerals of early formation is not incompatible with the magmatic origin of the analcite.

Another point in favour of the primary nature of analcite is the fact that it is often found, in igneous rocks, in large spherical areas surrounded by the other minerals. (*Cf.* Evans, 1901, p. 49.) The latter are usually ranged in a tangential fashion and seem to have been pushed back by the growing analcite. These areas usually contain no crystals of any other mineral, but in a few Ayrshire rocks, numerous very fine needles of green amphibole, which probably represent resorbed and recrystallized ferromagnesian material, are found.[2] The form of these indicates that crystallization took place under conditions of fairly high viscosity, and thereby the conditions offer a contrast to those obtaining in the analcitized Bute rocks where the viscosity must have been low. The difference between the two cases lies in the fact that in the latter the amount of silicate molecule was low in proportion to the amount of water, while in the former there was probably just sufficient water to give analcite.

The high degree of idiomorphism of the pyroxenes and amphiboles of a rock so rich in analcite as lugarite is also against the secondary origin of the last-named mineral. It is most improbable that either felspar or nephelite could be so corroded and replaced as to have entirely disappeared, while the ferromagnesian minerals show no trace of alteration whatsoever. Furthermore, in some of the Scottish examples, the felspars are unaltered and the nephelite shows characteristic decomposition products which are definitely not analcite, so that if the latter is secondary, it must have been derived from some felspathoid such as leucite or sodalite. As no trace of these has been found in these rocks, it is much more probable that the mineral is primary.

[2] The minute crystals of ægirine, which also occur in some of these "analcite areas," had probably a similar origin.

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The great abundance of analcite and its co-occurrence with certain particular types of pyroxene and hornblende are other points strongly in favour of the primary nature of the mineral. Thus the pyroxene of analcitic rocks is ægirine in the case of acid rocks, and deep-purple titanaugite in basic rocks, while the amphibole is either a green soda-hornblende or brown barkevikite. This suggests not only that the analcite is primary but also the particular type of magma from which it is likely to crystallize. The presence of such alkaline types of pyroxene and amphibole indicates a high magmatic content of soda at the commencement of crystallization and hence renders it unnecessary to postulate the introduction of soda, by percolating solutions or otherwise, for the production of the analcite.

Amongst the Ayrshire rocks, the mesostasis consists of felspar, nephelite and analcite. In the absence of magmatic water, the groundmass crystallizes as plagioclase and nephelite; if water is present, analcite, formed by combination of albite and nephelite molecules, also occurs. Even an excess of water, however, does not result in all the available normative nephelite and a corresponding amount of albite combining to form analcite, since the presence of anorthite molecules and the earlier formation of plagioclase must exert an influence on the equilibrium. One notable fact is that analcite is generally, in the rocks of the Lugar sill, at least, accompanied by a large amount of apatite, pointing to the presence, during the cooling of the magma, of mineralisers. It is significant in this respect that in the rocks of Alnö which contain primary calcite, this mineral is usually accompanied by large amounts of apatite (Workman, 1911, p. 196).

Practically all the synthesis of the mineral have been carried out by hydrothermal methods and at temperatures below 500°. Doelter claims to have prepared anhydrous soda-leucite by dry fusion, a result which the writer found impossible to obtain. Numerous fusions were carried out, but the resulting product always consisted of nephelite and glass or carnegieite and glass, according to the temperature of crystallization.[3] Hence it is doubtful if an anhydrous felspathoid of the composition $NaAlSi_2O_6$ exists. Furthermore, the co-existence of plagioclase and nephelite

[3] These experiments were made during the tenure of a Carnegie Research Scholarship.

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in so many igneous rocks is against the idea of such an anhydrous mineral being stable, at least at the temperatures of consolidation of igneous rocks.

The possibility of primary analcite has recently been advanced by the discovery of rocks containing abundant porphyritic analcite. Washington (1914, p. 749) has found it in a number of basaltic rocks from Sardinia, while MacKenzie (1914, p. 19) has described a remarkable rock, blairmorite, containing 71°/₀ of analcite. Although Pirsson (1915, p. 233) has suggested in the latter case that the mineral is a secondary product after leucite, there seems little doubt of its primary nature, the phenocrysts forming under plutonic conditions. So long as the pressure is sufficiently high for the water to remain in solution in the magma, there seems no reason for postulating a secondary origin.

So far as the evidence of the Scottish rocks[4] goes, there is little doubt regarding the primary nature of analcite. The relatively great abundance of the mineral, its structural relations to the other minerals of the rocks, and the evidence of analcitization are all against the view that it is secondary in such rocks as analcite-syenite, crinanite, teschenite, lugarite, essexite, and theralite, while there is similar evidence from foreign localities regarding the mineral in many other rock types.

[4] The writer is indebted to Mr. G. W. Tyrrell for the loan of slides of the analcite-rocks of Ayrshire.

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No. III.—The Horizon of the Type Specimens of Dithyrocaris tricornis, Scouler, and D. testudinea, Scouler. By Peter Macnair, F.R.S.E., F.G.S.

[Read 11th November, 1915. Issued separately, 28th November, 1916.]

Introduction.

The exact locality and as a consequence the precise geological horizon from which the type specimens of *Dithyrocaris tricornis* and *D. testudinea* were obtained has long been a matter of considerable uncertainty, especially to the members of this society who interest themselves more particularly in palæontological matters. These fossils, which are now preserved in Kelvingrove Museum, were first described by Dr. John Scouler in the Records of General Science for the year 1835 (p. 137). The object of this paper is to demonstrate that these fossils came from what was known as the Gallowhill Quarries, and that they occupy a position near the top of the Blackbyre Limestone of this district.

Regarding the beds in which they were found Dr. Scouler says, "This limestone is situated about a mile to the east of Paisley, and was first pointed out to me by Mr. Murray, of the Glasgow Botanic Gardens. This rock is distinct from and probably reposes on the true Carboniferous Limestone, but as only a small patch of it is exposed, the greater part being covered by the soil, it was impossible to trace its relations with the subjacent strata. This limestone is of an extremely compact nature, with little plates of calcareous spar disseminated through its substance. It readily splits into flags of variable thickness, which are sometimes made up of a multitude of extremely thin layers, indicating that the whole stratum has been formed by the gradual and tranquil deposition of transported matters. The organic matters differ widely from those which we observe in the Carboniferous Limestone, I could detect no *Productidæ* nor any fragments of corals or stems of crinoid animals, nor, in short, any decidedly massive production. Instead of these, on splitting up the rock we observe

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impression of ferns of great variety and beauty, the remains of entomostraca, which are of gigantic size when compared with the analogous species which still abound in our lakes and pools. Two species belonging to a new genus were obtained, and the numbers might have been greatly increased had not the hardness of the rock rendered the extraction of the specimens a difficult task." It will be noted that though in the above account no definite locality is mentioned, yet they are recorded as coming from a locality about a mile to the east of Paisley. Another important feature of this account is that it is such an exact description of the nature of the limestone in which the fossils occur that we can have no hesitation in identifying it with the bed to be described in the future part of this paper.

In the New Statistical Account of Scotland published in 1845, under the section "Town and Parishes of Paisley," we find the following important reference to this limestone and these fossils (1845, p. 157). It is of very great interest, because it appears to have hitherto escaped notice, and because it cites the Farm of Gallowhill as the exact locality where the fossils were obtained. The reference runs as follows:—"To the north-east of Paisley, on the Farm of Gallowhill, a quarry has of late been wrought in an extensive bed of schistose rock lying almost horizontally about 3 feet below the surface. Its colour is dark grey approaching to black. Its texture is compact and fine grained, and it readily splits into layers, but is with difficulty broken across. The fracture is splintery and rather conchoidal. It is composed of about 32 per cent. of carbonate of lime, 47 of sand, and 9 of alumina. This rock abounds in beautiful specimens of many genera and species of ferns, as also of shells, chiefly Terebratula, Nucula, and Orthoceratites. The layer of till immediately above this rock for several inches closely resembles Fuller's earth." The most interesting point, however, bearing upon the locality from which Scouler obtained his fossils is contained in the following footnote, which is added, "Two species found here belonging to a rare genus are described by Dr. Scouler in Thomson's Records of General Science, vol. i."

In 1865 Mr. James Armstrong (1865, p. 74) states in a paper published in the *Transactions* of this Society that specimens

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of *Dithyrocaris* were obtained by Dr. Scouler upwards of thirty years ago in a limestone excavated for the foundations of the Paisley Barracks.

In a paper read to the Society in 1893 Mr. James Neilson (1893, p. 71) makes the following statement regarding the locality where the type specimens of *Dithyrocaris tricornis* and *D. testudinea* were found:—"It is worthy of notice that when the late Dr. Scouler first discovered *Dithyrocaris* at Inkerman, near Paisley, nearly the entire animal was got. These beds were afterwards lost, and during many years since, the finding of only one or two carapaces has been recorded." From this it will be seen that Mr. Neilson, in utter disregard of any of the foregoing statements as to the locality at which the specimens were got, has shifted it to Inkerman, 1½ miles west of Paisley. But he gives us no reason for his doing so, and I am utterly unable to understand upon what grounds it was made.

In their memoir on the British Palæozoic Phyllocaridæ Professor T. Rupert Jones and Dr. Henry Woodward (1898, p. 147) still further complicate the matter, for in the text they say that Dr. Scouler's original specimen of *Dithyrocaris testudinea* is in hard, black, earthy limestone from the Carboniferous Limestone Series about a mile to the east of Paisley, the latter part of the sentence being quoted from Dr. Scouler's paper. But in a footnote they say, "At a place now called Inkerman, where Mr. R. Dunlop has lately most obligingly sought for further indications of these fossils, but without success." In this footnote they have evidently been misled by Mr. Neilson.

As we have already said, we hope to show that the statement made by the authors of the Statistical Account is probably the correct one, and that the specimens were got in a peculiar limestone which was formerly quarried on Gallowhill Farm, 1½ miles to the north-east of Paisley, and that both Mr. Armstrong's and Mr. Neilson's statements as to the locality where they were found are erroneous.

The Type Specimens of Dithyrocaris tricornis and D. testudinea.

The type specimens of the two species of *Dithyrocaris* were originally presented to the Anderson College Museum by Dr.

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Scouler, and some years ago were gifted, along with other specimens, to Kelvingrove Museum by the Governors of the Royal Technical College. *D. tricornis* shows the two valves of the carapace lying in an almost symmetrical position, but reversed so that the anterior part is approximately in the position that the posterior part ought to be, a phenomenon not unusual in decaying and floating phyllopods. The three somewhat

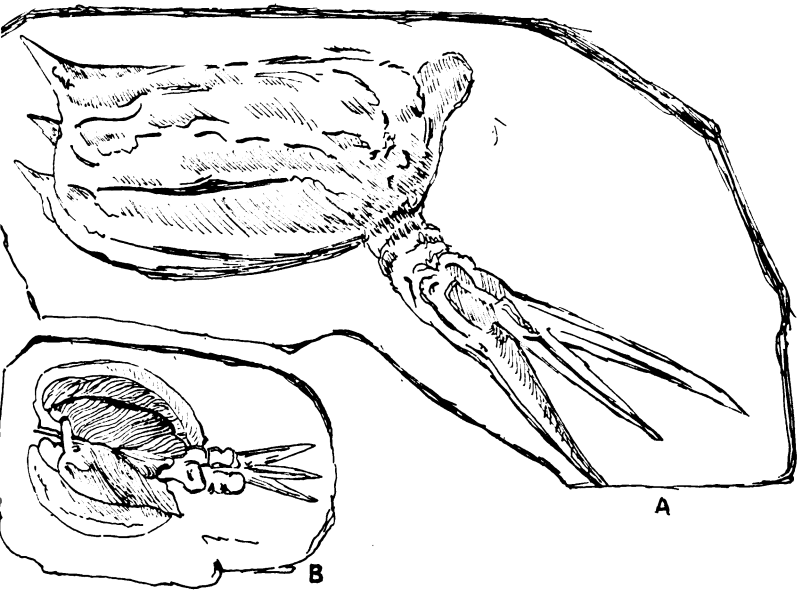

Fig. 1.—A. Dithyrocaris tricornis, Scouler. B. D. testudinea, Scouler. From the original drawings in Scouler's paper. The original specimens are now in Kelvingrove Museum.

obscure abdominal segments and a tail with three spines project from the lower part of the front of the carapace. The gastric teeth are exposed through the test.

In *Dithyrocaris testudinea*, the broad oval carapace is semi-elliptical in shape. The two valves lie in opposition by their dorsal edges, and overlap irregularly towards the lower half of the dorsal region. In both valves the central border is seen to terminate in a small obscure spine. A strong ridge showing the characteristic rugose structure of the overlapping chevron-

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shaped scales runs down the middle of each valve. The abdominal segments which project from behind the carapace have been considerably crushed. The three caudal spines are well shown. They are of nearly equal length, stout, fluted, and show traces of granulation on the riblets. Fig. 1, which shows *Dithyrocaris tricornis* and *D. testudinea*, is after the original drawing in Dr. Scouler's paper.

The only other fossil preserved on the slabs containing the type specimens is a single specimen of *Lingula mytiloides*, which is seen on the large slab with *Dithyrocaris tricornis*. As we shall presently see, this is the commonest of all the fossils found in the Gallowhill Limestone, in which it is often exceedingly numerous.

The Gallowhill Limestone.[1]

About two years ago my attention was first directed to the peculiar character of the limestone that forms the wall to the east of Gallowhill, near Paisley. The locality from which Scouler's type fossils had been obtained had for a long time exercised my mind, as it had done that of other local geologists, and when I first saw the limestone of which the wall is built I was at once struck with its strong similarity to that forming the matrix of the Scouler fossils. I took a specimen of the limestone with me, and a comparison of it with the specimens in the museum at once confirmed their identity. Both present the same earthy-like appearance, their joint faces being lined with calcite, and strongly charged with iron pyrites in nodular masses and in strings and isolated cubes. Associated with the limestone are bands of a much more argillaceous and sandy nature, of which examples may be seen in the dykes and bings, the large bing to the south of Gallowhill House having yielded numerous examples of the different types of sedimentation that appear to have prevailed upon this horizon. I am indebted to Mr. R. S. Houston for the following analysis of the limestone, which, like the analysis given in the Statistical Account, shows

[1] It should be clearly understood that the local term "Gallowhill Limestone" used throughout this paper does not stand for any new limestone horizon, but is only used to express a peculiar phase occurring at the top of the Blackbyre Limestone. This, indeed, is the main object of the paper.

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that it contains a large percentage of siliceous and clayey matter:—

Carbonate of lime,	48·67
Carbonate of magnesia,	·98
Carbonate of iron,	5·70
Alumina,	1·02
Siliceous matter (clay),	40·23
Carbonaceous matter,	2·30
Moisture,	·57
	99·47

After convincing myself of the lithological identity of the two limestones I began to search for some evidence of a phyllopod fauna, and was soon rewarded by clear evidence of its presence. Nothing to equal Scouler's specimens has yet been found, but fragments of carapaces and tail spines are sufficiently numerous and in a similar state of preservation to conclusively demonstrate the identity of the Gallowhill Limestone with that which forms the matrix in which Scouler's fossils are preserved. The most abundant fossil in the Gallowhill Limestone is *Lingula mytiloides*, many of the slabs being simply crowded with them. The full significance of the faunal association found in the Gallowhill Limestone will, however, be discussed in more detail presently. In his paper Scouler refers to the absence of *Productidæ*, corals or stems of crinoid animals, but *Productus longispinus* and *Rhynchonella pleurodon* are fairly abundant on some slabs. Slabs of the limestone rich in crinoidal remains have also been observed. But whether these represent the same bed as that which carries the phyllopod fauna or one on a slightly different horizon we have not yet been able to determine definitely, but we are inclined to favour the latter view.

Arkleston Cutting and Former Exposures at Gallowhill.

In my paper on the Hurlet sequence in North Ayrshire I have given an account of the strata exposed in the Arkleston Cutting, and it is there shown that the top limestone is the Hurlet Limestone, here 3 to 4 feet thick and dipping towards the

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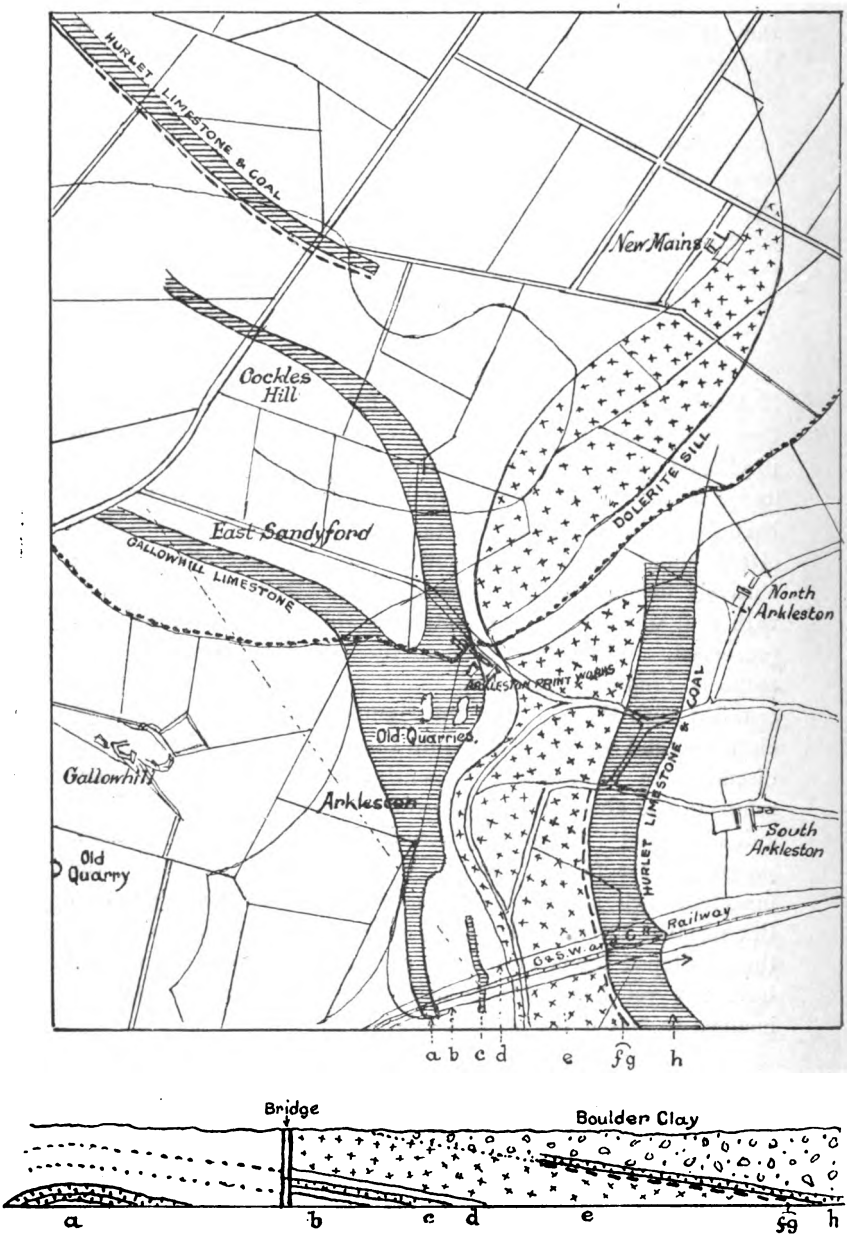

Fig. 2.—Sketch Map and Section along the Railway at Arkleston, Paisley.

a Blackbyre Limestone with Gallowhill Limestone phase at top. *b* Cementstone with rootlets. *c* Entomostracan Limestone. *d* Shales and fireclay. *e* Dolerite sill. *f* Hurlet Coal. *g* Alum Shale. *h* Hurlet Limestone.

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east. Below it comes the Hurlet Alum Shale, only some 6 inches thick, followed by the Hurlet Coal, originally from 5 to 6 feet thick. The coal has been split up the centre by a sill of dolerite, some 80 feet in thickness, lenticles of the coal occurring within the sill. Below the sill comes some 18 feet of shale and fireclay, in which there is a limestone in three seams full of entomostraca and fish remains, and which is clearly the equivalent of the Baldernock Limestone of the Campsie district. The whole group of sedimentary strata is much pyritised and altered by contact with the intrusive sill of dolerite. A search for the alum shale fauna in the fragments that are seen to lie above the sill has not as yet been successful in yielding any examples of that characteristic fauna, as the shale is very completely baked. But the discovery of the fauna at this point is not yet regarded as entirely hopeless. I have also shown in the paper mentioned that a highly fossiliferous limestone was at one time exposed between the bridge and the signal box, and that, dipping towards the east, it passed beneath the strata in the cutting just described. A consideration of all the available palæontological and stratigraphical evidence goes to show that this limestone must have been the equivalent of the Blackbyre Limestone.

If we turn to the 6-inch-to-the-mile Geological Survey map, of which Fig. 2 is in part a reproduction, it will be noticed that the limestone, there shown as trending northwards towards the Arkleston Print Works and then bifurcating into two outcrops towards the north-west, clearly lies below the sill now seen in the cutting. When the Geological Survey map was made in the year 1875 the railway ran through a tunnel at this point, and the Hurlet Limestone lying above the sill does not appear to have been exposed. If it was it is not indicated on the map. The limestone represented on the map is drawn as two narrow outcrops at the Paisley end of the tunnel. Unfortunately no exposure can now be observed between the bridge over the railway and the signal box. But that a limestone was at one time exposed at this point is made clear both by the Survey map and by Mr. Blair's paper published in our *Transactions* (1889, p. 139). In this paper Mr. Blair describes it as exhibiting "a wider variety and more abundant quantity

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of delicate organisms than I have yet seen in any of these deposits."

The section between the railway bridge and the signal box at the Paisley end of the cutting is now so completely grassed over that not a vestige of rock can now be seen, and we are left to judge by analogy with the general sequence of the district what the horizon of the limestone formerly exposed at this point may be. Fortunately, though exposures are extremely rare upon this horizon in this district, yet the cumulative evidence is such as to leave no room for any doubt in our minds that the limestone formerly exposed at this point, known locally as the Gallowhill Limestone, must be the equivalent of the Blackbyre Limestone of the Hurlet type section. On the east side of the railway bridge the lowest bed seen in the railway cutting is a band of grey cement limestone with rootlets, which all over this area is a well-marked horizon lying immediately below the Hurlet Coal and above the Blackbyre Limestone. It can be seen at Crookston Farm cropping from below the dolerite sill in exactly the same fashion as it does in this cutting, but there in addition to the rootlets it contains fish teeth, *Spirorbis*, and entomostraca.

Below this rooty cementstone there comes in the Hurlet district a variable thickness of shales succeeded by the Blackbyre Limestone. This view has been expressed in the section in Fig. 2; *a* is the Gallowhill Limestone, being the top of the Blackbyre Limestone, shown as folded into a gentle arch, which gives off in its eastern limb, *b* the cement limestone with rootlets, *c* thin bands of limestone with entomostraca and fish remains, *d* beds of shale and fireclay, *e* intrusive sill of dolerite, *f* and *g* Hurlet Coal and alum shale, and *h* Hurlet Limestone.

As has already been stated, no exposures of the Gallowhill Limestone can now be seen at any of the localities where it was formerly worked. But the position of two of the quarries south of the Arkleston Print Works can still be seen. Another quarry appears to have been opened a little to the south of Gallowhill, opposite the Mote Hill. The positions of these quarries are indicated on the map, and they seem to have been somewhat extensively worked about the year 1835, when Scouler's fossils were found, the old Powder Magazine between Arkleston and

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South Arkleston having been built of it, as well as a large number of the dykes in the Gallowhill Policies. It was also used in some walls in the neighbourhood of the Paisley Barracks, where it can still be seen. This may have something to do with Armstrong's statement that Scouler's fossils were found in a limestone excavated for the foundations of the Paisley Barracks.[2] That the Gallowhill Limestone must extend considerably to the west of the outcrop, as drawn on the map, is made clear both from the evidence derived from the old quarry opposite the Mote Hill and also from recent information that we have obtained which shows that Gallowhill House rests upon it. But whether it is continuous over this area or is repeated by faulting we have no data to decide, and the position of the outcrop is left much as it is given in the 6-inch-to-the-mile Geological Survey map.

The statement in the Statistical Account that the layer of till immediately above the Gallowhill Limestone for several inches closely resembles Fuller's earth is of great interest, as we seem to recognise in this the peculiar ashy fireclay which is generally found to rest on the eroded top of the Blackbyre Limestone of Renfrewshire and North Ayrshire.

In interpreting the structure of the ground between Arkleston and the Cart it seems to us that there must be a low arch bringing in the strata that lie immediately below the Hurlet Limestone. On the east this arch sinks below the Hurlet Limestone, as exposed in the Arkleston Cutting, and on the west it must pass below the outcrop of the Hurlet Limestone and Coal which has been drawn by the Survey to cross the White Cart Water near Carlisle Quay and Nethercommon. An exposure of limestone underlaid by a bed of coal with pyrites can at present be seen at low tide immediately below the Swing Bridge at Carlisle Quay, but owing to the limited nature of the exposure it is at present difficult to determine whether this is the Hurlet Limestone or the Blackbyre Limestone, but it is certainly the equivalent of one of these.

Bores put down along the outcrop of the dolerite on the

[2] Since writing this paper I have been informed by Mr. R. Houston that in making the foundations for the villas adjoining the Paisley Barracks it was found that slabs of the Gallowhill Limestone had been used to fill up old hollows in the surface of the ground.

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Gallowhill Policies show that the dolerite rests along this line upon a series of thick-bedded shales, fireclays, and sandstones which have been bored into for a depth of more than 30 fathoms. There can scarcely be any doubt that the uppermost of these represent the sediments which lie between the Blackbyre Limestone above and the Hollybush Limestone below. On the 6-inch-to-the-mile Geological Survey map a bore put down to the south of Gallowhill shows the presence of a coarse limestone 1 foot 7 inches thick at a depth of 12 fathoms. This is probably upon the position of the Hollybush Limestone.

Comparison with the Blackbyre Limestone at other Localities.

From the evidence that has been adduced there can be no doubt that the Gallowhill Limestone must lie somewhere on the horizon of the Blackbyre Limestone, and we now pass to consider the evidence that exists bearing upon the lithological and palæontological characteristics of the Blackbyre Limestone in this district. At the type locality (Blackbyre Farm) the Blackbyre Limestone consists of two parts, a lower full of small brachiopods, largely *Productus longispinus*, and an upper part which is crinoidal. Neither of these, however, can be compared with the Gallowhill Limestone. As a rule, the Blackbyre Limestone of this district may be described as essentially a brachiopod or shelly limestone with occasional bands of *Lithostrotion*. The contention of this paper is that the Gallowhill Limestone is simply a phase characteristic of the top of the Blackbyre Limestone, and as the top of the limestone is not seen at the type locality it is quite possible that it may be present though not exposed.

The section exposed at Jenny's Well, a quarter of a mile to the east of Blackhall, Paisley, is practically a counterpart of that seen in the Arkleston Cutting, and the additional corroborative evidence bearing upon the relationship of the Gallowhill Limestone to the Blackbyre Limestone is so complete that it requires to be examined in some detail. The section shows a fairly continuous sequence from the Blackhall Limestone down to the base of the sill of dolerite which here occupies exactly the same stratigraphical position as in the Arkleston Cutting,

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having the Hurlet Limestone above and the Blackbyre Limestone below.

Unfortunately the outcrop of the Blackbyre Limestone cannot be seen, but its position is shown by a hollow immediately to the west of the dolerite sill, which runs in a north and south direction from the Cart up the side of Dykebar Hill, marking the line along which it was formerly quarried. Just at the point where the road crosses the railway the Blackbyre Limestone was exposed during the making of the line. It cannot now be seen, but the walls on each side of the railway at this point are built of it, and the blocks of limestone show all the features of the Gallowhill Limestone on the one hand and of the Blackbyre Limestone of the type section on the other.[3]

An examination of the exposure of the Blackbyre Limestone seen in the bed of the Levern at Neilston, a little above the point where it crosses the main road to Lugton, helps, we think, to throw some light upon the relationship of the Gallowhill Limestone to the Blackbyre Limestone. The section here is somewhat obscure, but the main mass of the limestone is rich in corals and *Productidæ*. The former are represented by bands of *Lithostrotion* and solitary corals, the latter by various species of *Productus* and by numerous specimens of the large variety of *Productus giganteus*. On the top of the main mass of the limestone rests a bed of fine-grained cementstone, which presents all the features of the Gallowhill Limestone. Traced into North Ayrshire, it forms the peculiar fine-grained top of the Dockra Limestone and its equivalents, which we have elsewhere shown to be the same as the Blackbyre Limestone of the Hurlet section.

An examination of the sections exposed in the burn at Meikle Corseford, and on the Gryffe Water below Bridge of Weir, also affords certain evidence which goes to confirm the relationship of the Gallowhill Limestone to the Blackbyre Limestone. At both localities the Blackbyre Limestone is capped by a fine-grained crinoidal limestone comparable to the crinoidal phase of the Gallowhill Limestone. And at both these locali-

[3] The evidence derived from these blocks shows that the Blackbyre Limestone of this locality has a strong resemblance to that exposed in the Beith Quarries. It carries a varied brachiopod fauna and contains thick bands of *Lithostrotion* and other corals.

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ties it is overlaid by the peculiar green ashy mud which is probably identical with the so-called Fuller's earth found in the Gallowhill Quarry.

The Faunal Association of the Gallowhill Limestone.

The fauna of the Gallowhill Limestone is an exceedingly characteristic one, and has a remarkable resemblance to that which exists on a much higher stratigraphical horizon, the Calderwood Cementstone of the East Kilbride district. So striking is the similarity between the two that we here institute a comparison between them to show that they must have been accumulated under closely similar physical conditions. Both in the Calderwood Cementstone and the Gallowhill Limestone the fossils are but sparingly distributed throughout the limestone, and the rarer forms only occur at wide intervals. The following list gives some of the principal species that occur in the Calderwood Cementstone at such localities as Burnbrae, Jackton Burn, Kirktonholm, Glebe Quarry, and Limekilns House.

Serpulites carbonarius, M'Coy.
,, *membranaceus*, M'Coy.
Spirorbis caperatus, M'Coy.
Dithyrocaris glabra, Woodw. & Eth.
,, *granulata*, Woodw. & Eth.
,, *ovalis*, Woodw. & Eth.
,, *testudinea*, Scouler.
,, *tricornis*, Scouler.
Palæmysis, Peach.
Palæcrangon, Salter.
Palæsquilla Pattoni, Peach.
Anthrapalæmon Coutsii, Peach.
Discina nitida, Phill.
Lingula squamiformis, Phill.
Productus semireticulatus, Mart.
,, *longispinus*, Sow.
Rhynchonella pleurodon, Phill.
Streptorhynchus crenistria, Phill.
Aviculopecten knockonniensis, M'Coy.
Posidonomya corrugata, Eth.
Nuculana attenuata, Flem.
Protoschizodus æquilateralis, M'Coy.
Nucula gibbosa, Flem.
Sanguinolites plicatus, Portl.
Orthoceras attenuatum, Flem.
Nautilus, sp.

Serpulites carbonarius occurs in the Calderwood Cementstone, some slabs being simply covered with the tubes of this worm. In the Gallowhill Limestone they occur in exactly similar conditions. I have also found traces of *Serpulites membranaceus* and *Spirorbis caperatus* in the Gallowhill Limestone.

The phyllopod crustacea from the Gallowhill Limestone include, besides the two species *Dithyrocaris tricornis* and *D. testudinea*, others whose specific characteristic have not yet been determined. Their mode of occurrence and state of preservation are strongly suggestive of the conditions under which these fossils appear in the Calderwood Cementstone. No traces of the schizopods

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which occur in the Calderwood Cementstone have as yet been found in the Gallowhill Limestone, but further search may yet reveal the presence of some of these most interesting forms.

The brachiopod fauna of the Gallowhill Limestone is strikingly similar to that of the Calderwood Cementstone. In the Carluke district the Calderwood Cementstone is known as the Lingula Limestone, because of the large numbers of that fossil which occur in it. In the Gallowhill Limestone *Lingula squamiformis* is replaced by *Lingula mytiloides*, which, as has already been pointed out, occurs in great numbers. The more common brachiopods in the Gallowhill Limestone are *Productus longispinus*, *P. semireticulatus* and *Rhynchonella pleurodon*, and less commonly *Discina nitida* and *Streptorhynchus crenistria*.

Lamellibranchs are exceedingly scarce in the upper part or estuarine phase of the Gallowhill Limestone, but several specimens referable to *Sanguinolites plicatus* have been found, and one specimen closely resembling *Protoschizodus æquilateralis* and *Posidonomya corrugata* also occurs, and from the lower and more crinoidal parts *Nuculana attenuata* and *Nucula gibbosa* have been obtained.

The Cephalopoda are represented in the upper or estuarine part of the limestone by *Orthoceras attenuatum* and by a *Nautilus* which has not been specifically determined.

Fish remains, in the shape of scales, spines, and plates, occur in the upper part of the limestone, though in a somewhat fragmentary condition. They are clearly referable to those ganoids which are found in the estuarine facies of the Carboniferous Formation.

Plant remains are fairly common, principally the fronds of ferns, and occurring as they do in association with the phyllopods, and with *Productus longispinus* and other brachiopods they tend to accentuate the resemblance between the Gallowhill Limestone and the Calderwood Cementstone.

From what has been said it will be seen that the whole assemblage of plants and animals found in the Gallowhill Limestone is strikingly similar to that which occurs in the Calderwood Cementstone. That these strata are of estuarine origin is made clear by the manner in which the remains of land plants

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and animals are intermingled with those of estuarine and marine types, just as we find in estuarine deposits at the present day.

I have to acknowledge my indebtedness for much assistance in working out the details of the Gallowhill district to Mr. Wm. Holmes, of Sandyford.

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No. IV.—Dry Channels in Glen Lednock. By Alexander Scott, M.A., D.Sc.

[Read 13th January, 1916. Issued separately, 28th November, 1916.]

Introduction.

The valleys of the Scottish Highlands are usually divided into two groups (Geikie, 1901, p. 186, Mackinder, pp. 127-8); (*a*) The transverse consequent valleys which trend north-west and south-east and which represent the drainage lines of the old Highland tableland; (*b*) The longitudinal valleys which trend north-east and south-west and which follow more or less the strike of the underlying rocks. In the Southern Highlands, the chief representatives of the former are Glen Garry, with Strath Tay from Ballinluig to Dunkeld, Strathfillan, Glen Ogle and the tributaries of the Earn, Glen Turret and Glen Lednock; of the latter Glen Dochart with Loch Tay, Glen Lyon and Strath Bran.

Several of these transverse valleys show considerable evidence of being anterior to the longitudinal depressions, for they cut through watersheds, and are often very large in proportion to the streams which occupy them at present. While Glen Ogle is one of the best known of these through valleys, Glen Lednock, together with Finglen which enters the Tay Valley at Ardeonaig, is probably also along the line of a former transverse valley, since, not only is the watershed between the two glens lower than the mean level of the watershed between the Tay and the Earn, but, as will be shown in the sequel, this watershed cannot have been lowered by the present streams. The valleys must have been initiated by a consequent stream which arose to the north-west of Loch Tay, and which has been partly obliterated by the longitudinal valley of the latter.

The Lednock rises on the south-west slopes of Creag Uichdag and, after a south-easterly course of twelve to fourteen miles, enters the Earn at Comrie. A consideration of the thalweg of the stream (Fig. 1) shows that it may be divided into several "flats" with falls or "rapids" intervening. The river falls somewhat steeply from its source until a level of 1100 feet is reached, when the gradient becomes slight. After a "flat," four miles long,

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there is a sharp fall (Spout Rolla) followed by two more flats separated from each other by a slight "rapid." The lower part of the stream consists of the gorge known as the De'il's Cauldron, where the gradient is again steep.

Description of the Channels.

Spout Rolla and the Allt Mathaig Channel.—There is nothing remarkable about the upper part of the course. The stream arises from the coalescence of several small burns which drain the flat col between Glen Lednock and Finglen. This col is uniformly flat at a height of 1600 feet for about a mile and is flanked by hills several hundred feet higher. Its relatively great breadth precludes any possibility of lowering by the present streams, and

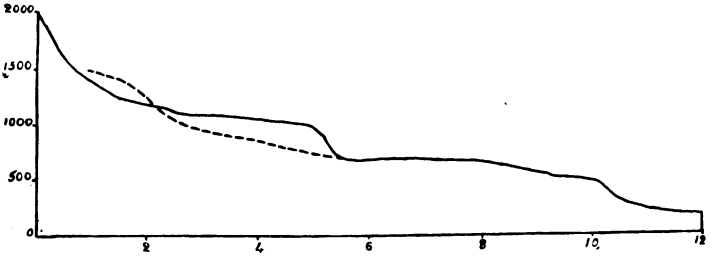

Fig. 1.—Thalweg of River Lednock. The dotted line represents the thalweg of the Allt Mathaig. Vertical height in feet and horizontal distance in miles.

this, in conjunction with its evident valley-form, favours the idea of its formation by a former river of much greater magnitude. After descending to 1100 feet, the stream meanders through the flat alluvial floor of a broad U-shaped valley. This floor was occupied by a lake before the outlet at Spout Rolla had been cut down to 1100 feet. The north and south fault, which brings the schistose grit against the softer mica-schists in which the upper part of the valley is cut, may have been one of the factors which determined the origin of the lake. At Spout Rolla, the stream turns southward and, after falling 300 feet, joins another stream from the north-west, the Allt Mathaig, and then turns south-east again. As the Allt Mathaig is the smaller stream, we have thus a hanging valley larger than the one into which it enters. The two valleys

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are approximately parallel to each other for some distance, and then the larger stream turns at an angle of 45° and falls into the other. Looking north-west from a point on the road one-half mile below the junction, the Allt Mathaig seems to be the main valley,

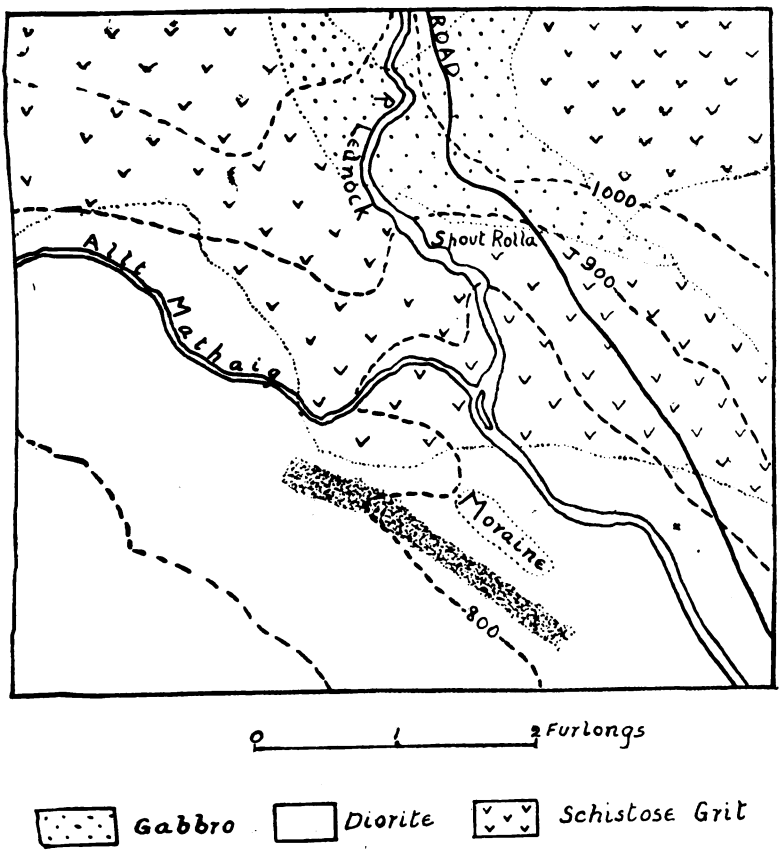

Fig. 2.—Geological Sketch Map of the neighbourhood of Spout Rolla. The shaded area shows the trend of the dry channel. Reproduced, with additions, from the 6″ Ordnance Map, by permission of the Controller-General of H.M. Stationery Office.

the upper Lednock being invisible. The barrier which holds up the latter stream is a large mass of foliated gabbro, the exposure of which is of an irregular crescent form with the concave side facing upstream (Fig. 2), and it is the superior resistance of this

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which is responsible, in part at least, for the higher level of the Lednock.[1] It is, however, possible that Glen Mathaig has been overdeepened by glacial action, the great abundance of moraines, compared with their comparative scarcity in upper Glen Lednock, pointing to more vigorous ice-action in the former.

For some distance above and below the junctions of the streams a wooded ridge, 80-100 feet high, divides the floor of Glen Mathaig into two channels, the eastern one being occupied by the present stream while the western one is dry (Fig. 2). The latter, which is well-defined for one-half mile, is obviously a former channel of the Allt Mathaig, and when it was occupied, the junction of the two streams must have been two furlongs south of the present one. The two channels are very similar in form, but they differ in that the dry one is entirely in the diorite area, while the eastern

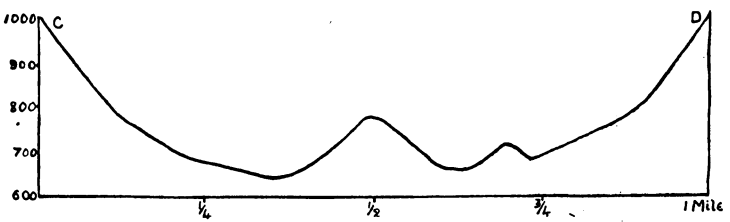

Fig. 3.—Section across Glen Lednock along the line C.D., fig. 4. Vertical height in feet.

one is partly in schist and partly in diorite. There is no evidence of blocking up by moraines, although the latter are numerous further up Glen Mathaig, while a long medial moraine forms a prominent continuation of the wooded ridge separating the two channels. The most plausible explanation is that the westerly channel was cut down through the schist roof until the diorite was reached, and a north-north-west recession of Spout Rolla being in progress at the same time, this induced the partial diversion of the waters of the Allt Mathaig, the final abandonment of the western channel being determined by the superior resistance of the diorite.

The Funtullich Channels.—Below Spout Rolla the valley

[1] Masses of gabbro-schist and amphibolite form similar barriers in the streams to the north-west of Loch Freuchie.

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widens out until, at the junction with the Innergeldie burn, it has a broad, flat floor one-half mile in width. This "flat" is the site of a former lake, and shows traces of terraces, while three well-marked channels lead outwards on the southern margin, two of these having floors above the level of the lake floor (Fig. 3). Of

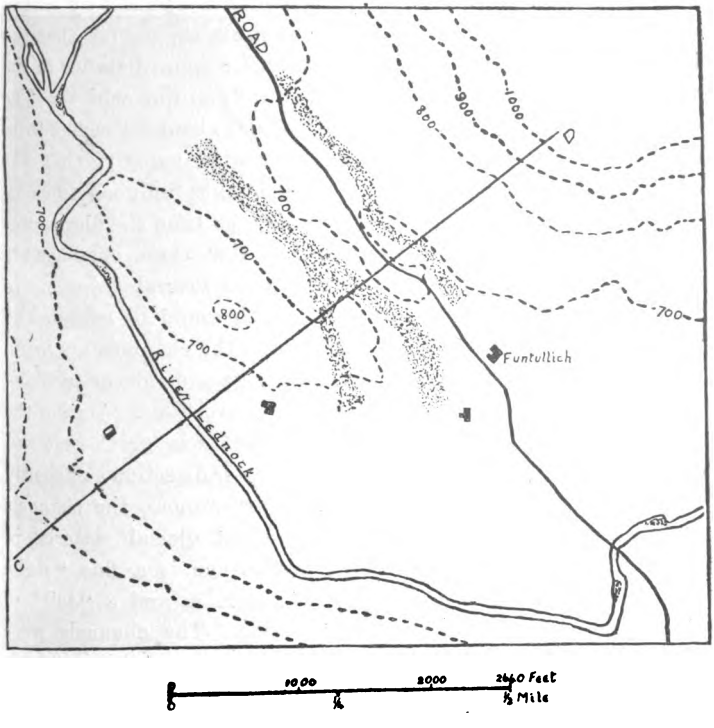

Fig. 4.—Sketch Map of the neighbourhood of Funtullich. The shaded areas show the trend of the dry channels. Reproduced, with additions, from the 6″ Ordnance Map, by permission of the Controller-General of H.M. Stationery Office.

the three channels the deepest is the western one, which is at present occupied by the stream, while the most easterly has its floor at a higher level and is not so well-marked as the others. The middle one, however, is a straight deep trench with a flat floor and steep sides, the whole belonging to the type characterised by Bonney (1915, p. 9) as "railway-cutting trenches." About half-

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way down it bifurcates, and a side channel leads southward. All three channels, which disappear in the alluvial flat south of Funtullich, are cut through rock, and from east to west represent successive channels of the river. The eastern channel is entirely in diorite; the middle one seems to lie along the margin of the intrusive rocks, as at its southern end diorite overlain by schists is exposed, the low angle of dip of the schists suggesting that the igneous rock continues at no great depth for some distance to the west; while the western channel is entirely in the schists. The explanation of the abandonment of the dry channels seems to be similar to that of the Allt Mathaig example, namely, that the differential resistence of the diorite and schist induced the outflow from the lake to migrate westwards each time the diorite was reached. An alternative explanation is that these channels are overflows from a glacier-lakes but there are several objections to this. The forms are scarcely those which would be expected to result from the action of lake-overflows as the channels are broad and deep, with flat floors, and indicate a stage of maturity which would not be attained if they were due to overflows. During the main glaciation the trend of the ice-sheet was north-west and south-east, and there is no barrier in the latter direction sufficiently high to form a lake of any depth. Furthermore, the channels are possibly pre-glacial; there is abundant glacial material in them, and near the mouth of the middle one is a fine "roche moutonée" with the glaciated surface upstream and a "tail" of glacial material on the downstream side. The channels were probably filled with débris during glacial times, and this may have been cleared out by the action of overflows from the lake during the period of melting of the valley glaciers. The mature form of the channels, however, suggests that these were cut in pre-glacial times and hence the first explanation seems more satisfactory.

The Lurg Channels. — The three channels described above debouch on another alluvial "flat" which is lenticular in shape, and may have been formed by lateral corrosion by a meandering stream or may represent a former lake. This also has several well-marked exits (Fig. 5). The one at present occupied by the stream is the most easterly and is a narrow gorge, as the stream is entrenching itself deeply in the diorite. One-half mile to the west, however, is a well-marked channel which, for the greater part, is

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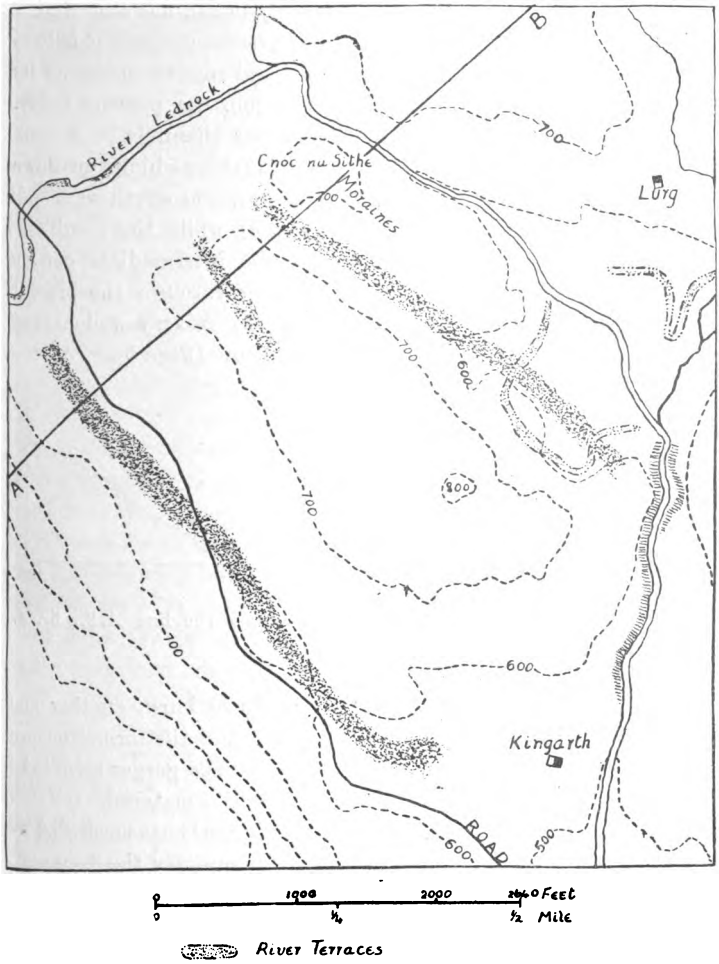

Fig. 5.—Sketch Map of the Lurg Channels. The shaded areas show the trend of the dry channels. Reproduced, with additions, from the 6″ Ordnance Survey Map, by permission of the Controller-General of H.M. Stationery Office.

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occupied by no stream and which must be a former channel of the Lednock. This valley, which is obviously river-cut and shows occasional terraces, is comparatively broad, has a maximum depth of 200 feet, and is parallel to the present gorge. It follows generally the line of contact of schist and diorite unless at its lower end where it turns eastwards to join the present valley. Between these two there are several other channels. A well-defined trench occurs on the east side of the ridge which runs down the middle of the glen. The floor is flat, the south-west wall steep and over 100 feet in height (Fig. 6), while the north-east side is only extant at the two ends, the intermediate portion having been elided by the stream flowing through the present channel before the initiation of the gorge. A very well-marked terrace indicates the course of this stream (Fig. 5). At the

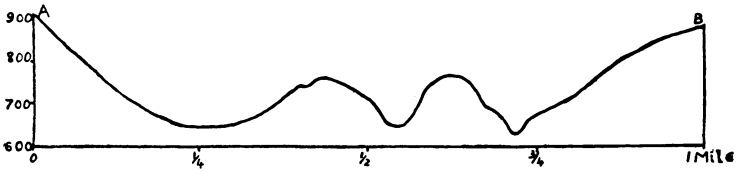

Fig. 6.—Section across Glen Lednock along the line A.B., fig. 5. Vertical height in feet.

junction of the main stream with the Lurg burn, another fine river-terrace is visible.[2] Both above and below the former terrace the river is entrenching itself in diorite, and the gorges seem to be post-glacial as their sides are capped by glacial material.

The Balmuick Channels.—The above channels are succeeded by another alluvial patch and then the river traverses the deep post-glacial canyon of the De'il's Cauldron. This is a deep, narrow gorge with vertical walls, the depth being several times the width. From here to the 300 feet contour the valley is V-shaped with steep sides, and is mainly cut out by pot-hole action, numerous water-worn surfaces and large pot-holes being

[2] The presence of these meandering terraces on the sides of the gorge indicates a rejuvenation in comparatively recent times. This may be due to some slight movement or to the rapid down-cutting in the De'il's Cauldron.

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visible high up on the valley walls. Many of the pot-holes have been 12-15 feet deep, while a number of large fallen blocks indicates that a certain amount of undercutting has taken place. The geological structure is one which is very favourable to the initiation of pot-holes. The country-rock is schistose grit, dipping north-west at an angle of 80° (*Cf.* Nicol, 1863, pp. 190-2), so that the stream is cutting across the strike and perpendicularly to the foliation planes. As the hardness of the beds varies greatly, the stream exerts a differential action, small hollows being easily eroded in the softer bands of the floor and walls, and the lodgment of pebbles and boulders in these results in the formation of pot-holes. The course of the stream is partly determined by two fairly large dykes.

The pre-glacial course seems to have been further east, where there are two parallel dry valleys, both of which have been occupied by the Lednock (Fig. 7). One, which is a well-defined river-cut channel, about 80 feet deep, starts near the De'il's Cauldron, and after trending south-east disappears at the 300 feet contour on the north side of the Earn valley. This seems to have been a high-level channel of the Lednock before the De'il's Cauldron was cut through, but later than the abandonment of the valley further east. The disappearance of the valley at the 300 feet contour line suggests that the Earn was at this level when the Lednock drained into it through this channel.

Some distance north of De'il's Cauldron two broad, dry trenches, running east and west, lead to the Milton burn. There is little doubt that the Lednock formerly flowed in these channels, one of which is directly continuous with the most westerly of the channels described on page 66. The course of events has been rather complex here, but the following is the probable sequence. The Lednock originally flowed down the western "Lurg" channel, and then through the channel at Balmuick and down the course of the Milton burn; at later periods this course was abandoned, and the channel further south and then that through Laggan wood successively occupied until finally the gorge of the De'il's Cauldron was initiated, probably by a small stream cutting back along the line of the present gorge but at a much higher level. Meanwhile another stream cutting back up the abandoned channel captured the head waters of the Milton burn which at that period must

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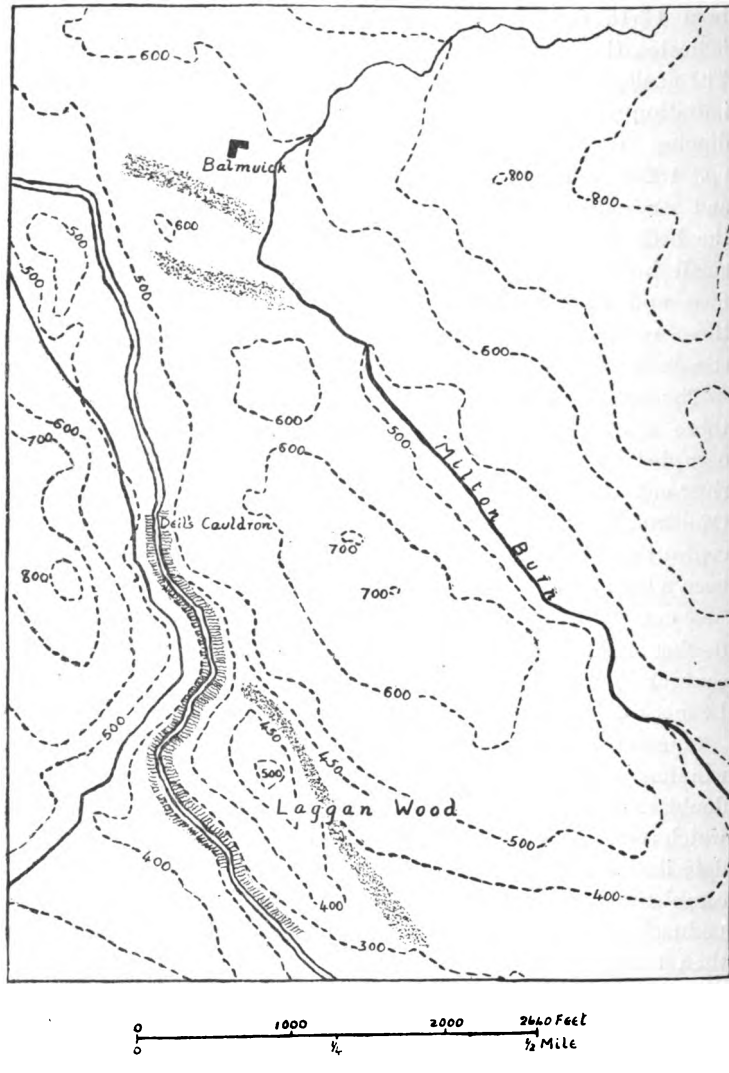

Fig. 7.—Sketch Map of Lower Glen Lednock. The shaded areas show the trend of the dry channels. Reproduced, with additions, from the 6″ Ordnance Map, by permission of the Controller-General of H.M. Stationery Office.

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have been a tributary of the Lednock. This is borne out by a consideration of the heights of the various channels. The western Lurg one falls from 630 feet at its highest point to 560 feet where it enters the alluvium west of Kingarth. The cross Balmuick channel has its floor approximately on the 540 feet level, while a bench-mark a short distance down the Milton burn indicates a level of 530 feet.

Causes of Abandonment.—There are thus several sets of dry channels in Glen Lednock, some of them leading out of former lake basins. Such basins are, of course, common in the Southern Highlands, as, for example, the well-marked ones in Glen Falloch (Geikie, 1901, pp. 175, 199) but, so far as the writer is aware, no other glen shows such a wealth of abandoned channels. The existence of gorges between the basins is also a notable feature in many Highland Valleys. (*Cf.* Geikie, 1901, pp. 263-4.) The abandonment of the channels is to be explained in various ways. The differential resistance of the surface rocks is the chief factor in the case of the channel below Spout Rolla, while the superior resistance of the diorite seems responsible for the Funtullich series. This latter explanation will not hold in the case of the Lurg gorges, since the lowest, which is the one at present occupied by the stream, is cut entirely in diorite while the most westerly one is along the junction of the plutonic rocks with the schists. The most probable explanation is that the present gorge was initiated by the Lurg burn and that a tributary of the latter finally cut to the Funtullich lake and diverted the drainage, the fall in this direction being rather greater than that in the dry channel. Differential resistance is probably the potent factor in the case of the Balmuick channels. The old course down the Milton burn is partly in the diorite area and partly along the indurated aureole of schist which abuts on the diorite,[3] while the channels further to the west are in the unaltered schists. The gorge of the De'il's Cauldron is possibly along a line of weakness, as in one place there is some evidence of shattering; the presence of the dykes has also had some influence in determining the course of the stream.

[3] The schists near the diorite contact are often indurated, and several of the minerals which are typical of contact-metamorphosed rocks are found in them.

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Age of Glen Lednock.

With regard to the age of Glen Lednock, few data are obtainable. The evidence of Kainozoic dykes such as is obtained in the case of Loch Lomond is lacking, as the only dykes of this age in the glen are found in the gorge below the De'il's Cauldron, which seems to be mainly post-glacial. The youngest rocks exposed in the glen are the diorites, which are probably of Old Red Sandstone age. The superficial deposits, likewise, do not yield much information. The chief deposit is composed of fine unstratified sandy material, full of angular pebbles and apparently glacial in origin. This is often overlain by a coarse fluviatile deposit with an abundance of water-worn pebbles. Locally the fluviatile gravel is superimposed on a fine stratified boulderless deposit, while fluvio-glacial material is also common. The greater portion of the glen is certainly not post-glacial, deposits such as lateral and terminal moraines being common. It is also probable that one or two of the prominent scars on the west side of the glen may be examples of incipient spur truncation.

The valley, as a whole, is almost certainly a relic of one of the early consequent valleys. The size is large in proportion to the stream, and it exhibits all the characteristics of the "Open Valley" (Rich, 1914, p. 470). The course is straight, as are also the walls, and the stream tends to swing across the valley-floor in broad curves, which are independent of the course of the valley. The stream meanders locally, in those parts where down-cutting is prevented by the presence of hard barriers on the down-stream side. While the dry channels undoubtedly owe their origin to the present stream, the valley itself must have been cut by a much larger river. The alluvial flats are contemporaneous with the channels or, at least, with the existence of a stream like the present one, for otherwise the valley would be expected to show contractions between the basins. It is impossible to fix the age of the dry channels. They have been formed by a stream similar to the present one and flowing in the bottom of a flat, open valley. They are subsequent to the development of the watershed between the Tay and the Earn, and hence younger than the longitudinal valleys; some of them are possibly pre-glacial and were filled with débris in glacial times and cleaned out again during the melting of the ice.

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Again, the col between Glen Lednock and Finglen cannot have been much lowered by the present stream, since it is fully one mile broad, and not a sharp ridge such as would arise by the lowering action of streams. Either a col such as this must be part of the floor of an older through valley or, if it is due to lowering by two streams flowing in different directions, the streams which formed it must have reached base-level. In the present case, the juvenile vigour of both the Finglen burn and the Lednock at the edges of the col negatives such a possibility, and hence the former must be the correct explanation. Thus it seems feasible to assume that the two glens were cut down, in part, by one river, and it is possible that the deep glen on the north side of Loch Tay, which contains Lochan na Lairige, was also initiated by the same river. The watershed between the Lyon and Tay at Lochan na Lairige is at a level of 1800 feet, while that between the Tay and Earn at the head of Glen Lednock is at a level of 1600 feet, so that there is evidence of a fall in this direction. The initiation of the longitudinal valley of Loch Tay was no doubt responsible for the cutting-off of this river, and it was at a period subsequent to this that the dry valleys in Glen Lednock were cut.

The existence of the numerous moraines and other glacial deposits on the floor of the valley is evidence that by the end of Glacial times, at latest, the main portions of the valleys had been excavated. That it is also pre-glacial is very probable as there is no evidence of deepening during Glacial times The only two tributaries of any size, the Innergeldie burn and the Lurg burn, both enter the Lednock nearly at grade and neither is in any sense a hanging valley. If the main valley had been over-deepened to any extent by ice it would be expected that these tributaries would be left hanging. Their existence in Glacial times is shown by the presence of both medial and terminal moraines in the case of the Lurg burn (*cf.* Buckland, 1840, p. 335), and by the partial obstruction of the Innergeldie burn by similar deposits. Even though these valleys were filled by tributary glaciers, they are so small in proportion to the size of Glen Lednock that it is difficult to see how, if there was any appreciable down-cutting by ice, they could maintain their grade, and their level keep pace with that of the main valley. It is probable that

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the valley attained its present form, to a great extent, in pre-Glacial times, but with regard to its earlier history and to the influence of the great uplift in late Tertiary times, there is, of course, no direct evidence.

The author is indebted to the Carnegie Trustees for defraying the cost of the illustrations.

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No. V.—A Jurassic Shore Line. By M. Macgregor, B.Sc., H.M. Geological Survey. Photographs by Mr. R. Lunn, H.M. Geological Survey.

[Read 13th January, 1916. Issued separately, 28th November, 1916.]

Introduction.

It was the intention of Dr. Crampton, late of H.M. Geological Survey, and of the present writer to describe in detail the Jurassic rocks of the Helmsdale-Brora coast. Owing to Dr. Crampton's ill-health and his retiral from the Survey this project had to be abandoned. To the present writer has fallen the task of preparing from his own field notes a short account of the most remarkable feature in the geology of this district. The reader will readily understand in the sequel how far this account fails of being complete, and how Dr. Crampton's unrivalled knowledge of the sequence of the Middle Old Red Sandstone of Caithness would have added much-needed detail and colour to the bare outline given. For errors of observation and for mode of treatment the writer is wholly responsible; the conclusions are offered as a joint contribution to Scottish geology.

The remarkable conglomerates exposed on the East Sutherland coast north and south of Helmsdale have long attracted the attention of geologists. They have been described in notable papers by Murchison, Judd, and Blake, and several interpretations have been advanced to account for the peculiar phenomena they show. The following paper, while embodying some fresh evidence bearing on the origin of these deposits, attempts also to give a summary of preceding work.

Previous Literature.

Murchison.—In the summer of 1826 Murchison, while examining the secondary deposits of East Sutherland, was struck with the singular appearance of the "brecciated beds." Describing the shore section at Port Gower, he (1827, p. 305) says, "In consequence of the powerful disturbing forces which have

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been in action, some of the beds most affected here and along the shore to Kilmot are made up of portions of shale and sandstone mixed with the shelly limestone, thus forming a conglomerate." Of the section at Navidale he (1827, p. 307) writes, "It has been frequently remarked that, wherever the granite rock appears, the beds in contact with it are elevated, and in many instances shattered into fragments; hence it would seem that such phenomena can only be explained by supposing the former to have been thrown up at periods subsequent to the deposition of the latter."

Murchison and Sedgwick.—Murchison returned to the ground in 1827 in company with Sedgwick. In a joint paper the authors (1828) reaffirm Murchison's opinion already given that the brecciation is due to the mechanical action of the granite.

Hay Cunningham.—In a paper on the geology of Sutherland Hay Cunningham (1839), while rejecting Murchison's theory, offers one no less impossible. Referring to the "conglomerate composed of variously sized masses of the sandstones, shales, and limestones of the (Oolite) series," he says, "This may be easily explained by supposing that after the deposition of some of the strata they were acted on by destructive agents and again reconsolidated."

Hugh Miller.—Miller seems to have been the first to prove from their organic contents that the included rock masses of the boulder bed belonged to a much earlier formation than the Jurassic, namely to the Old Red Sandstone. In 1827 Murchison (1827, p. 306) had written, "Other geologists may be of opinion that some of these indurated shales with an associated limestone have been derived from the slate of Caithness, which is very largely developed to the north of the Ord; but such an inference can hardly be admitted, since the latter alternates with the sandstone of the red conglomerate, elsewhere shown to be composed of those granitic and older rocks, of which latter there is not a vestige in this singular breccia." Miller, however, definitely proved the point. In his "Testimony of the Rocks" he writes, "In the water-rolled pebbles of the conglomerate of Helmsdale and Port Gower—pebbles enclosed in a calcareous paste containing Oolitic belemnites and ostreæ—I have found the well-marked fishes and fucoids of

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the Old Red Sandstone." He calls attention to the similarity of the "pebbles" to the rocks of Caithness, but advances no theory to account for their presence in the "conglomerate" of Helmsdale. "Water-rolled" is quite a misleading description of these remarkably angular boulders.

Ramsay.—In 1859 Murchison and Ramsay visited the Brora-Helmsdale coast, and Ramsay, in a paper on the "Glacial Theory of Lake Basins" (1865, p. 293), refers to the boulder bed of East Sutherland as having "possibly, though not probably, a glacial origin."

Judd.—It is to Judd (1873, pp. 187-95) that we owe the most complete account of the Jurassic rocks of East Sutherland and of the associated "boulder beds." In this classical paper on the Secondary rocks of North-east Scotland he gives a very faithful description of this remarkable deposit. He describes the nature, the material and the fossils both of the matrix and of the included blocks. He mentions the theories of Murchison, of Hay Cunningham and of Ramsay, only to dismiss them, but his own conclusions leave the question still an open one. He leans to the view that a solution to the origin of the "boulder beds" may be found in some combination of violent river floods and glacier action, but admits the difficulties that such a view leaves unsolved.

Bonney.—In a paper entitled "On the Relation of Certain Breccias to the Physical Geography of their Age," Professor Bonney (1902, pp. 201-2) mentions the Jurassic breccias in the Upper Oolite of East Sutherland. "They seem," he says, "to be the product of a mountain district with a heavy rain or snow fall during part of the year, possibly also with glaciers." He suggests that they resemble in some ways the breccias of the Alpine Flysch.

Blake.—In the same year appeared Blake's paper "On a Remarkable Inlier Among the Jurassic Rocks of Sutherland, and its bearing on the Origin of the Breccia Beds." Taking up the problem of the origin of the "boulder beds" where Judd had left it, Blake compared these singular deposits with the work of an ice foot. He (1902, p. 293) described an "inlier of Old Red Sandstone" exposed on the shore near Port Gower as "a kind of sea stack with its stratification vertical"; and

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compared it with the Needles of the Isle of Wight. The puckering seen at several places in the Jurassic muds at their point of contact with large boulders he explains as due to pressure from the north or north-east. His conclusion is stated thus (1902, p. 309)—"The breccia beds of Sutherland have originated in an ice foot, and they are the first recognised in this country as having such an origin."

Woodward.—Mr. H. B. Woodward surveyed the Jurassic rocks of East Sutherland for the Geological Survey, but no memoir has yet been issued to accompany the published 1-inch map (Sheet 103). In the discussion following Bonney's paper, and again after Blake's, Woodward stated that he saw no occasion for the introduction of ice action. The only published account of his view of the origin of the boulder beds is contained in a very brief description of the shore between Navidale and Lothbeg incorporated in Professor Seward's paper (1910, p. 646) on "The Jurassic Flora of Sutherland." It is quite clear from this account that Woodward regarded the boulder beds as a cliff talus or scree.

Geological Description.

The deposits described below are found along a narrow coastal strip between Ord point and Kintradwell (see Plate II.). They are associated with normal sediments of predominantly estuarine type—sandstones, shales, limestones, and thin coaly seams—whose fauna and flora show them to be of Upper Jurassic age. The boulder beds are best exposed along the shore between high and low tide marks from the Ord to beyond Navidale, and again from a little south of Helmsdale to Garty point. They are found also on the coast at Lothbeg and at Kintradwell, but in less striking development. To the eye they appear as a bewildering assemblage of rock masses and fragments piled up in extreme confusion, cemented by a calcareous matrix largely formed of comminuted shells, and resting frequently on dark fine-grained fossiliferous mudstones, which are often waved and contorted at the junction. Before enumerating the main features that a general examination brings out it will be well to describe in some detail a few typical localities.

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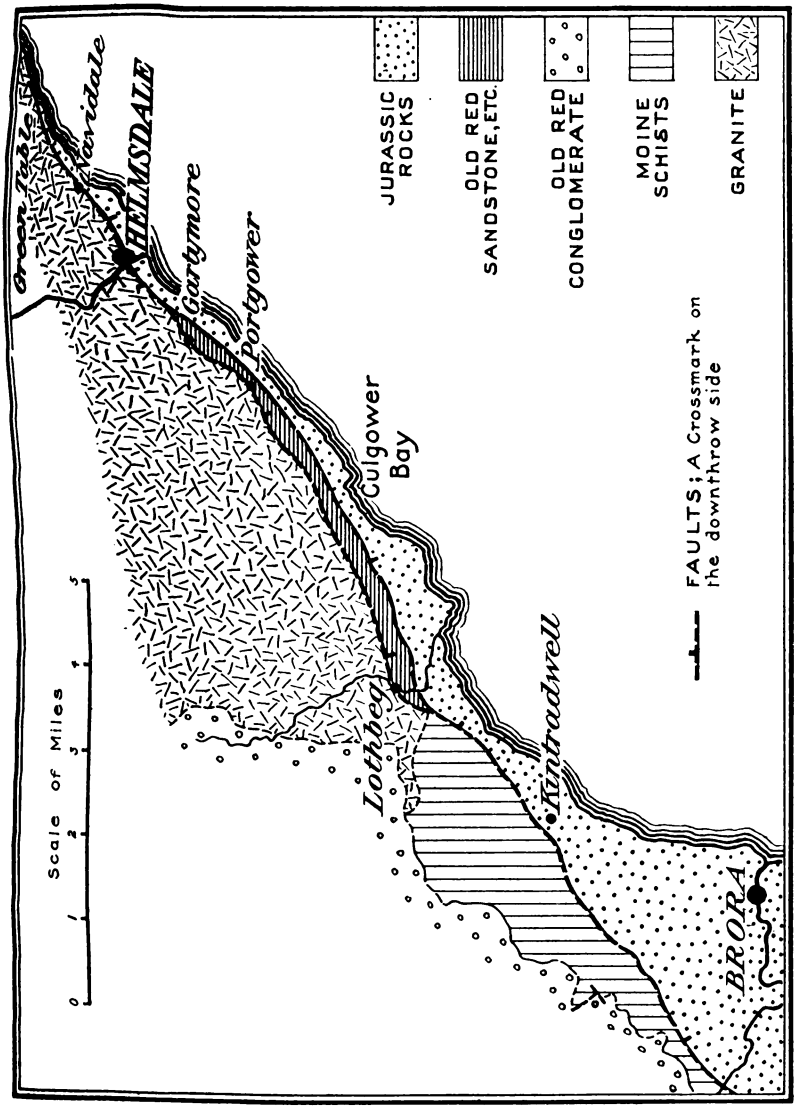

Sketch Map of Coast between Green Table and Brora; showing main Rock Groups.

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Section 1—*Shore between Greenpark and Gartymore Burn.*—The "boulder bed" is excellently seen along this part of the coast. The included "boulders" are, in the more north-westerly portion of the section, mainly of hard fine-grained sandstone associated with dark-brown flags containing fish remains. The "boulders" lie at all angles with their bedding planes now vertical, now horizontal, now oblique (Plate IV., Fig. 2). In size they range from small fragments up to blocks measuring $6 \times 4 \times 3$ feet. They vary greatly in shape, but are almost universally angular. The matrix is formed of shelly débris mixed with rolled quartz grains, and contains fragments of carbonised wood and streaks of coaly material. Recognisable shell fragments occur, and among these are Belemnites, species of *Isastraea*, *Pecten*, *Ostrea*, *Lima*, *Rhynchonella*, &c. Here and there are large specimens of *Isastraea oblonga*, 1 foot to $1\frac{1}{2}$ feet in diameter. Further south-east, towards Gartymore burn, the blocks are mainly of dark-coloured "fishy" flags along with some of limestone. They are again highly angular, and include masses of 7 to 10 cubic yards. The matrix here is more sandy, with well-rounded grains of quartz and comminuted fragments of shells. Along this section the boulder beds form ragged seaward-running reefs directed 15° to 20° east of south, and separated by strips of black muddy sediment.

Section 2—*Shore a Little South of Port Gower.*—This is perhaps the most convincing of the coast sections, and shows highly angular rock fragments of various sizes piled up like fallen masonry without the least order (Plate IV., Fig. 1). The prevalent type of rock is a carious-weathering limy sandstone. The matrix, partly shelly, partly siliceous, has a characteristic pitted and honeycombed appearance. One of the boulders measures $31 \times 7 \times 15$ feet, and rests on contorted muds; another containing ribs of impure limestone, is at least 40 feet long and 30 feet wide. The largest boulder noted—and the most interesting—in the whole coast section occurs here.[1] It is approximately 150 feet long and about 90 feet wide in its broadest part; in height it reaches some 30 feet. Its length is directed seawards, in which direction it gradually narrows.

[1] Also described by Blake (1902, pp. 291-4).

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Around it are found many other large rock fragments which at one time must have formed part of it (Plate III., Fig. 1). It is composed of soft sandstones, grey, green, and red mudstones, and bands of cream-coloured limestone. The bedding is vertical, and the bedding planes at some of the salients show fine sun-cracked and ripple-marked surfaces. A little further south along the coast good exposures of the shelly matrix are found. Largely composed of comminuted shell débris, it contains also beautifully rounded quartz grains and pebbles, Belemnites, Echinid spines, fragments of shells of species of *Ostrea*, *Lima*, *Rhynchonella*, *Cerithium*, *Ammonites*, &c. One almost complete Ammonite measured over 1 foot in diameter.

Section 3—*Ord Point to Navidale.*—Fine exposures of the boulder bed occur here again. It is at Ord point that the great fault which has lowered the Jurassic rocks against the granite and crystalline schists to the west reaches the sea. The fault can be seen in the little promontory known as the Green Table (Dun Glas). Here the boulder bed is upturned against the fault, and is thus proved to be of earlier date. On the shore just south of the Green Table the included blocks consist of—

(1) Light grey sandstones with sun-cracked surfaces.
(2) Dark flaggy sandstones.
(3) Light-coloured sandy limestones.

One hundred yards or so further south along the shore the blocks are mainly composed of flaggy red and grey mottled mudstones often as large as $10 \times 6 \times 4$ feet. Further south again this type is replaced by yellow and brown marly sandstones. The blocks along this section of the coast are very numerous, and lie heaped upon one another without the least order or arrangement. While practically all angular, they vary enormously in size and shape. Only a few among the smaller ones show an approach to roundness. The matrix is again composed of shell débris and rolled quartz grains, and contains fragments of wood and recognisable parts of Upper Oolite marine fossils. Near Navidale large specimens of corals—*Isastraea oblonga*—16 inches in diameter, are found in it.

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Age.

(a) *The Included Blocks of the "Boulder Beds."*—Hugh Miller (1854) seems to have been the first to point out that the fossil remains of the matrix and of the included blocks had nothing in common. Reference has been made above to his discovery in the latter of the "well-marked fishes and fucoids of the Old Red Sandstone." Among these he recognised *Osteolepis*. Judd (1873, p. 193) also records the finding in the blocks of "very numerous fragments of the Old Red Sandstone fishes," and among these fragments the Rev. J. M. Joass, of Golspie, detected the remains of *Osteolepis* and *Gyroptychius*. Apart from the fossil contents, the lithological characters of the blocks stamp them as indubitably belonging to the same geological series as the rocks of Caithness. The mottled sandstones, the soft sandy limestones, the sun-cracked and ripple-marked flags, the dark brown "fishy" beds, all remind one irresistibly of the Middle Old Red Sandstone of Caithness.

(b) *The Matrix.*—The matrix cementing the blocks is largely composed of comminuted shells, and is often so calcareous that it has in places been burned for lime. Enclosed in it can be found many recognisable shells and shell fragments which prove it to be of Upper Oolitic age, and to have been formed probably in late Kimmeridgian or early Portlandian times. The following species have been got:—

Isastraea oblonga, Edw. and Haime.
Rhynchonella Sutherlandiæ, Dav.
Perna quadrata, Phill.
Ammonites "biplex," Sow.

Species of *Ostrea*, *Lima*, *Cerithium*, *Pecten*, *Rhynchonella*.

Judd records also from the matrix—

Ammonites alternans, Von Buch.
Lima concentrica, Sow.
(Both Kimmeridgian species.)
Belemnites abbreviatus, Mill.
Cidaris spines.
Plesiosaurus vertebræ.

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Fragments of Cycad stems and leaves are also fairly abundant. North of Lothbeg Point the muds on which the boulders rest contain, according to Blake (1902, p. 297), "*Hoplites eudoxus*, or one of its allies, the horizon of which is near the base of the Upper Kimmeridgian, in Kimmeridge Bay." He records also the finding, near Port Gower, of *Ammonites biplex* from the same *Hoplites* beds, and points out that in the type Jurassic sequence the *Ammonites biplex* zone is followed by Lower Portlandian beds with such reef-building corals as *Isastraea oblonga*. In the muds north of Lothbeg Point Seward found such Kimmeridgian species as *Avicula aedilignensis*, Blake; *Lima concentrica*, Sow.; and *Ammonites alternans*, Von Buch.

Summary of Chief Features Shown by the Boulder Beds.

Before dealing with the origin of these deposits it will be best to summarise the leading features—

(1) The included blocks are exclusively derived from Middle Old Red Sandstone strata, such as are found in Caithness at the present day.

(2) The matrix is, on the other hand, of late Kimmeridgian or early Portlandian age.

(3) The blocks are extremely angular, as a rule, and are orientated at all angles to one another.

(4) They vary in size within wide limits.

(5) The larger ones at least are far from homogeneous in texture, and are sometimes broken and fractured as though by a fall.

(6) They are frequently seen resting on fossiliferous Jurassic muds, which are often waved and contorted along the line of junction.

(7) The matrix is of shell débris with a varying proportion of rolled sand grains.

(8) Its fossils are marine typically, but fragments of leaves and stems also occur.

(9) At any particular portion of the boulder beds the fragments are notably of the same lithological type, or show no greater variation than occurs frequently in vertical faces of the Caithness cliffs.

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(10) Finally, as one follows the boulder beds southwards the rock fragments appear to be derived from successively higher zones in the now well-established Middle Old Red Sandstone sequence.

Conclusion.

Murchison's conclusions were reached before the Old Red Sandstone had been established as a distinct formation and before anything was known of the age of the granites of the North of Scotland. The Ord granite was intruded long prior to Jurassic times, and the "brecciation" has certainly nothing to do with it. Glacial action does not furnish an adequate explanation for the following reasons:—

(1) There is no associated boulder clay and no glacial striæ.

(2) The boulders are too angular, and show too little variation in lithological type to have been due to carriage by ice.

(3) There is no evidence for the occurrence of a glacial period here in late Jurassic times. Indeed the evidence of the fossil flora indicates exactly the reverse.

Nor does it seem likely that river floods could convey a mass of rock consisting of mudstones, friable sandstones, and sandy limestones, and measuring 150 × 90 × 30 feet in extent, and deposit it *en bloc* along with others only slightly less large.

Strangely enough, while geologists were seeking an answer to the problem, the solution was being slowly written for them on the Caithness coast. A few miles north of these old Jurassic boulder beds Nature is repeating physiographical conditions closely similar to those under which they must have been formed millions of years ago. No one familiar with the Caithness cliffs could doubt that in the Helmsdale boulder beds we have preserved for us in fossil form a coast line of the Caithness type. Two illustrations of this type of scenery are reproduced among the photographs at the end of this paper (Plate V., Figs. 1 and 2). Cliffs of Old Red Sandstone strata rise steeply from the sea, showing walls of rock here

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hollowed out into caves, here interrupted by narrow and steep-sided inlets or goes. The sea, breaking along joint planes, has isolated great buttresses and pinnacles of rock from the parent cliffs. Fragments torn from these by the waves fall around their bases until some storm shatters them to pieces and strews their débris over the sea floor. Very similar must have been the conditions under which the Helmsdale boulder beds were formed. If we prolong in imagination the line of the Caithness cliffs south-westwards along the East Sutherland coast we can gather some idea of this old Jurassic strand-line. Here in late Jurassic times stood cliffs of Middle Old Red Sandstone strata, showing then, as the Caithness cliffs show to-day, all the wonderful features of stack and skerry and goe. The shores were washed then by seas haunted by large reptiles now long extinct, and the land bore a rich vegetation of cycads and ferns, some of which "have left descendants in tropical and subtropical floras of the present day" (Seward, 1910, p. 703). From these old cliffs great rock fragments fell into the sea at their base, and the effect of their impact on the soft muds is still startlingly clear (Plate III., Fig. 2; Plate IV., Fig. 1). The huge boulder on the Port Gower shore, described above, can surely be nothing else than an overturned stack, just as though one of the Duncansby stacks had been undercut and had fallen seawards (compare Plate III., Fig. 1 and Plate V., Fig. 1). This hypothesis explains also the angularity of the fragments, their variable size, their local uniformity of type, their association with a littoral marine fauna, and the presence of plant débris. From the fact that the boulders when followed from north to south come from successively higher zones of the Middle Old Red Sandstone sequence we might even postulate a southerly dip of the strata. It might also be suggested that where, as at Gartymore, we find the boulder beds forming seaward-running reefs separated by strips of black muds, the former represent the sides and the latter the centre of old Jurassic goes. Finally, these boulders furnish an additional proof of the fact that in Jurassic times strata of Old Red Sandstone age had a very much wider extension than they now have in the north of Scotland.

The cost of illustrating this paper has been defrayed by the Carnegie Trust for the Universities of Scotland.

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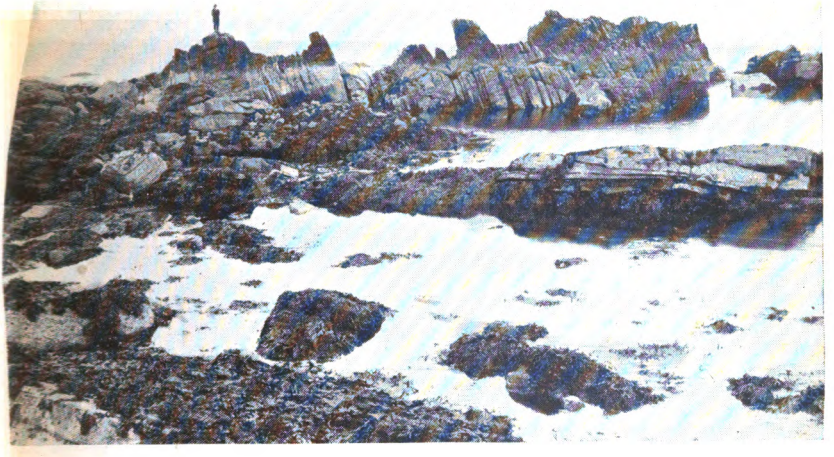

No. 1.—Fallen Stack ; shore, a little south of Port Gower.

No. 2.—Boulder-bed ; shore at Kintradwell.
Note disturbance in Jurassic muds caused by fallen boulders.

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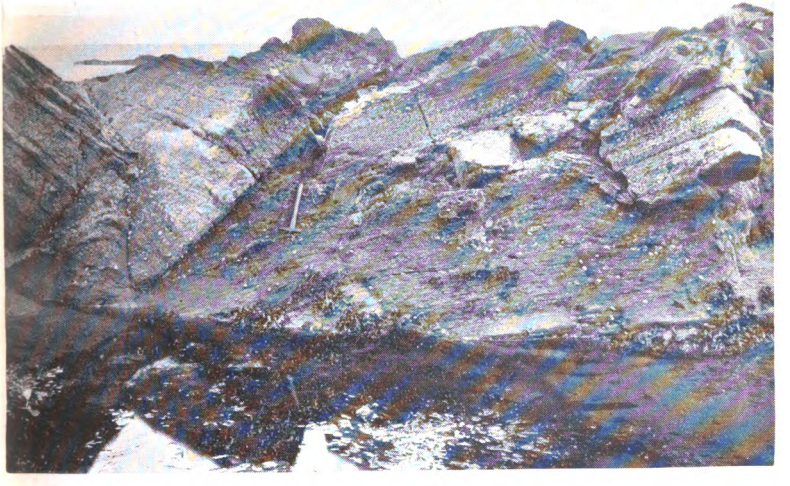

No. 1.—Shore near Port Gower; large boulders of Old Red Sandstone embedded in Jurassic muds.

No. 2.—Boulder-bed; shore, near Gartymore.

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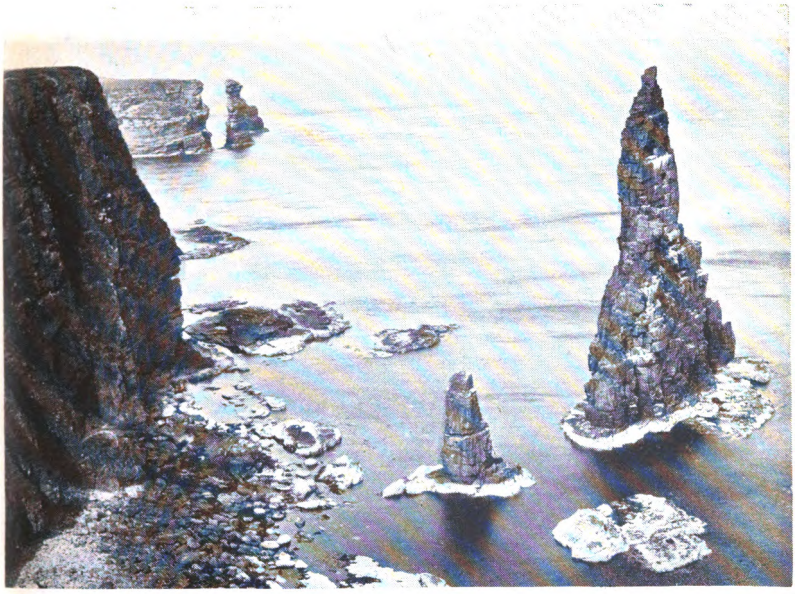

No. 1.—Duncansby Stacks, Caithness; looking north.

No. 2.—Castle Haven Goe, Castle Girnigoe, Caithness; right side of goe still quarried by sea.

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No. VI.—Preliminary Notes on Volcanic Necks in North-west Ayrshire.[1] By G. V. Wilson, B.Sc., F.G.S., H.M. Geological Survey.

[Read 9th March, 1916. Issued separately, 28th November, 1916.]

The area under consideration lies in the adjoining margins of the Geological Survey maps, sheets 21 and 22, Scotland, on which a large number of volcanic necks are shown to occur. Sir Archibald Geikie (1897, pp. 394 *seq.*; 1903, pp. 65-6), who has given several short accounts of them, considers that they are the sites of some of the volcanoes which gave rise to the Calciferous Sandstone lavas. During the recent revision of this area by the Geological Survey several new volcanic necks have been recognised, and fresh evidence has been gathered about some of the others. In the map of the district (Fig. 1) the various necks are each given a separate number, and for facility of reference the same numbers will be used in the following account.

Description of the Necks.

Vents Containing Acid Materials.—The Irish Law vent (No. 1) forms the south extremity of the great volcanic centre of Misty Law, and most probably represents a late phase of activity. Its margins are only seen on the west in the sections on the sides of Rye Water Head, where a coarse-grained pink and green volcanic breccia is in contact with a pink felsitic rock. Further north the margin can be seen cutting across the Gogo Water. To the south it has been traced in a south-easterly direction to the west slopes of Knockside Hills (Figs. 2 and 3). The eastern margin is covered by peat, but is taken as running in a north-easterly direction. Several masses of trachytic and basaltic rocks occur in the vent, interesting occurrences being on Irish Law. The breccia in the vent contains numerous trachytic fragments and therefore it looks as if the junction between the two rocks was of an explosive nature, with shattering of the already consolidated trachyte.

[1] Communicated by permission of the Director of H.M. Geological Survey.

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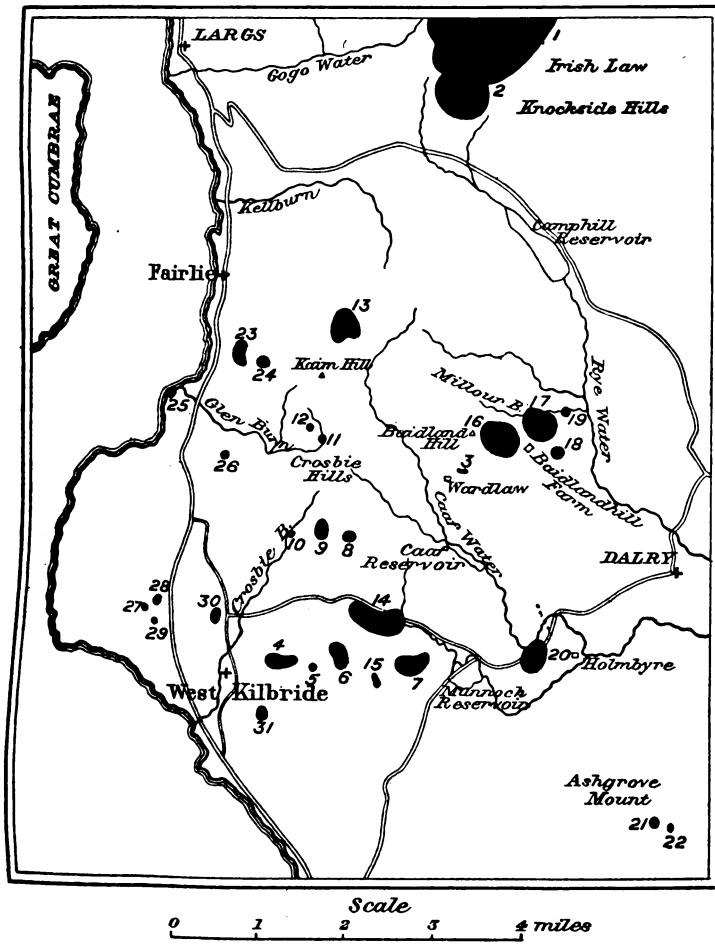

Fig. 1.—Map of the district showing the distribution of the necks.

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The Knockside Hills vent (No. 2) represents a later phase of activity than the Irish Law vent, and its margins are good on the south and west sides. A vertical junction between breccia and the lavas can be seen in Guillie burn. The nature of the north margin is obscure, and two alternative views are shown by Figs. 2 and 3. In Fig. 2 the shattering of the trachyte into breccia of Irish Law seen on Blair's Craigs is considered to have taken place on the sides of the crater, and the dip of the material of the breccia is taken as representing the scree formed by the falling away of the already solidified trachyte and earlier breccia to form the material of the later breccia in the crater of the volcano. In Fig. 3 the margin is drawn as a simple curve to the south of Blair's Craigs, where the breaking up of trachyte into breccia is considered an explosion phenomenon in the Irish Law vent, the dip of the breccia material being attributed not to surface screeing, but to the dragging down of material on the sides of the vent (underground) by the subsidence of the material in the pipe of the volcano. The summits of Knockside Hills are formed of trachyte. Unfortunately, the junction between this rock and the breccia is not seen, but in all probability it is similar to those in the Irish Law. A small but interesting exposure of basaltic rock approximating to the Markle type occurs on the east side of the largest mass of trachyte (see Figs. 2 and 3), and probably represents the consolidated plug of this type in the vent. The junction between this rock and the trachyte cannot be seen; hence no idea as to their relative age is obtainable.

A small trachyte plug (No. 3) cutting through the lavas about 250 yards E.N.E. of Wardlaw is the only other acid neck which has so far been met with.

Vents Containing Basic Materials.—The necks are divided into three groups as follows:—

(*a*) Necks cutting the Upper Old Red Sandstone.

(*b*) Necks cutting the Calciferous Sandstone lavas.

(*c*) Necks cutting the Carboniferous Limestone Series.

Group (*a*) comprises the following:—

No. 4, forming Law Hill, to the east of West Kilbride, consists of a dirty green, much-decomposed volcanic ash. It

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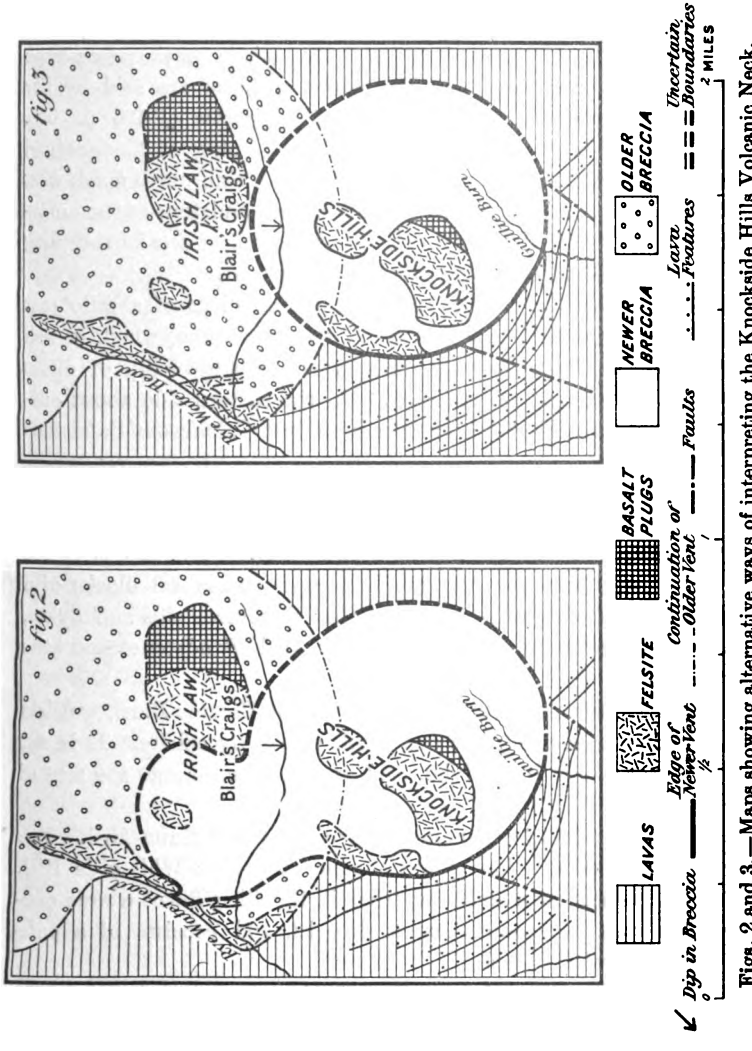

Figs. 2 and 3.—Maps showing alternative ways of interpreting the Knockside Hills Volcanic Neck.

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is interesting to note that it is cut by east and west quartz-dolerite dykes.

No 5 gives rise to a small rounded hump about 150 yards east of Law Hill, and consists of decomposed ashy material.

No. 6 forms Blackshaw Hill. The ash is of the same type as that of Law Hill, and fragments of blaes are said by Sir A. Geikie to contain specimens of *Spirorbis* (1903, p. 65). The very top of the hill is formed by a plug of fine-grained dolerite surrounded by ash, and is cut by a thin north-north-west basalt dyke. A large mass of highly baked sandstone at the north-west corner I am inclined to regard as a block of the surrounding Upper Old Red Sandstone caught in the vent.

No. 7, forming North Hill, about two-thirds of a mile east of Blackshaw Hill, contains ash of the same type, which is well exposed at the western margin, where a steady dip of about 40° into the vent can be seen. On the eastern side about one-quarter of a mile of the margin is against Calciferous Sandstone lavas.

Nos. 8, 9, and 10 occur on the south-west slopes of Crosbie Hills. Nos. 8 and 9 give rise to the two low green mounds of Greenside and Lairdside Hills respectively. The ash is of the usual type, and at Greenside Hill contains several blocks of a pale porphyritic felsite similar to that of several sills and dykes, occurring both in the Upper Old Red Sandstone and the Calciferous Sandstone lavas.

No. 10, forming a small exposure in the Crosbie Burn, consists of a dark green volcanic ash much veined by calcite. It is cut by a north-east basic dyke, and probably represents the site of a conelet.

Nos. 11 and 12 occur on the south slope of Kaim Hill. No. 12 gives rise to a low grassy mound known as Whiteside Hill. No. 11 is seen at a small exposure in the Glen Burn, about one-eighth of a mile south-east of No. 12, and consists of a pale-greenish volcanic ash.

No. 13, forming Lairdside Hill, to the north-east of Kaim Hill, consists of a plug of coarse olivine-dolerite. For a short distance the north-eastern margin is in contact with Calciferous Sandstone lavas.

Nos. 14 and 15, forming irregularly-shaped mounds, are two

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basalt plugs. The rock of No. 15 is of the Jedburgh type, but decomposed.

Nos. 23-31 have not yet been re-examined in detail.

Group (*b*).—The necks which cut through the Calciferous Sandstone lavas include the Baidland Hill group.

No. 16, forming the east side of Baidland Hill, consists of a dirty green-coloured volcanic ash when fresh, which weathers to a reddish spheroidal mass. Small crystals of biotite about one-quarter of an inch in diameter have been noticed in the ash, also numerous fragments of sandstone, trachyte, and various basalts. Exposures are not good, and the best occurs by the old well just west of Baidland Hill Farm.

No. 17 occurs just north and east of the farmhouse, and is exceedingly well exposed on the sides of Millour burn and its tributary. The ash when fresh is dark green in colour. It weathers red, and assumes a beautiful spheroidal structure. It contains numerous fragments of basalt, and also rare pieces of a garnetiferous rock. Several fragments of charred wood occur, and also large isolated rounded crystals of augite and hornblende, which, however, are too much shattered to extract whole.

The west wall of the neck is well seen in Millour burn. It has a steep inclination into the vent, and the surrounding lavas are much baked. The material for several yards next the side has a dip of about 60°, and large slabs and masses of sandstone, with rootlets and also streaks of coaly matter, can be seen mixed up with ashy layers. At the eastern margin, further down the burn, similar masses of sandstone occur. It is stated that a coal about 5 feet thick was once worked at an old day level in the corner of the field north of the farmhouse. The hole has now been filled up, but the roof was seen until quite recently, and consists of sandstone similar to that in Millour burn; thin ashy layers also occur. It therefore seems probable that this coal was also part of some seam let down into the vent, and not, as was previously considered, a coal interbedded in the lavas.

No. 18 gives rise to a small rounded knoll about 150 yards south of No. 17, and consists of very similar material.

No. 19 is exposed on the sides of Millour burn a few yards

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east of No. 17. It is only a few yards across, and probably represents the side of a conelet or cinder cone.

Group (*c*) comprises the following necks:—

No. 20, at the bend of the Caaf Water, near Holmbyre, forms a low rounded hill about one-quarter of a mile across, and cuts through the beds which occur just below the Highfield Limestone, and in all probability through the limestone as well. The material of the neck is a dark grey ash, which contains numerous rounded flat pieces of biotite up to one and a half inches across and half an inch in thickness. Numerous fragments of basalt of various types, and also of marine fossils such as *Productus* and *Euphemus urei*, occur embedded in the ash. No sign of any other rock such as blaes has been seen attached to or inside of these fossils, while a thin microscopic section cut through a specimen of the rock, with *Euphemus* embedded in it, showed the ash to penetrate into the whorls of the shell. This seems to imply that the ash is the original matrix of the shells, and if such is the case, it looks as though this was either a submarine volcano or one into which the sea occasionally had access. At the south margin of the vent a small highly basic intrusion occurs in the ash.

Nos. 21 and 22 form small mounds, the more westerly and larger one called Ashgrove Mount. The material in both is a dark decomposed volcanic ash.

The Age of the Necks.

The Acid Necks.—The Irish Law and Knockside Hills vents are probably the oldest in the district, though possibly some of the small basic necks scattered through the Upper Old Red Sandstone country may represent a still earlier phase of activity. If such an early basic phase existed, one might reasonably expect to find remnants in the shape of highly basic lava flows or ash beds, but, no such strata having yet been met with, the basic necks are for the present all taken as being of later date than the Misty Law centre, except perhaps the basic plugs, Nos. 14 and 15. The Irish Law and Knockside Hills vents are seen cutting through Calciferous Sandstone lava flows about 1000 feet above their base, so they are evidently later than the early lavas, and probably represent late outbreaks on the sides of

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the cone of the Misty Law volcano. The trachyte plug of Irish Law has a resemblance to some of the more acid lavas, and may be the core rock of some of the lavas away to the east and south-east. The Knockside Hills vent contains a small core of a variety of Markle basalt. Lava flows of this type are common, but none which are comparable to the trachyte plugs of this vent have been seen. It seems therefore that these necks may represent a late phase of volcanic activity during Calciferous Sandstone times.

The Basic Group of Necks.—The ash in the vents is nearly all of the same kind, *i.e.*, very basic in composition and usually much decomposed. It is also similar to that of the interbedded ashes which occur about the position of the Black Band Ironstone in the Dalry Basin. The appearance of large crystals of augite, hornblende, and biotite in some of the necks suggests analogies to the monchiquite dykes of Colonsay (Flett, 1911), which are considered to be of Permian age, and also to the rock from Carskeoch Hill, near Patna (Tyrrell, 1912, p. 78). The occurrence of the coal shows that the neck is later than the earliest Carboniferous coal-bearing rocks.

The neck (No. 20) near Holmbyre is of particular interest, affording one of the few cases where the geological age of a volcano can be fixed within narrow limits. It is seen cutting through the strata just below the Highfield Limestone, and probably cuts the limestone as well. The ash of the neck is the matrix of marine fossils, being the original material in which they were buried, thus showing that at the time they were incorporated they were probably loose shells lying on the sea bottom. They are of a type which is not later than early Millstone Grit. The first volcanic outburst probably took place in Upper Carboniferous Limestone times either as a submarine volcano in shallow water or as a small cone on a low-lying country which was occasionally submerged by the sea, when the cone would be breached and marine shells washed into the crater by the tide. If the quartz-dolerite dykes are of Permian age, as seems probable, the Law Hill vent (No. 4) must be pre-Permian. The Greenside Hill neck (No. 9) contains felsite fragments which are later than early Carboniferous.

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Of the three basic plugs, Nos. 14 and 15 may possibly be earlier than the Misty Law centre, but No. 13 is probably later, as it is seen cutting some of the basal lavas and also is more basic in composition than any of the lavas in the district. Summing these results, it looks as if most of the necks were of Carboniferous Limestone age, and that volcanic activity started about the time of the deposition of the Dalry Black Band Ironstone, and continued, in some cases perhaps intermittently, to the Millstone Grit period, giving rise to highly basic lavas of that age. There is no evidence of such activity during the deposition of the Coal Measures, but some miles further south-west necks and lavas of Permian age are well known.

H. H. Robinson (1913) gives an account of an area in the San Franciscan Volcanic Field, Arizona, which in some ways is suggestive of the Ayrshire district. His map shows six large volcanic cones, the highest (San Francisco mountain) rising up to 12,611 feet above sea-level and 5000 feet above the surrounding country. Round about this centre are scattered some 300 small basic lava and cinder cones, of which about 100 are considered to be earlier than the large volcanoes and the rest later.

The average height of the small cones is about 700 feet, though a few are over 1000 feet. In one case the crater is about a quarter of a mile wide and 400 feet deep. A conelet only 50 feet in height is also mentioned. A parallel might be drawn, and the large cones taken as the equivalents of the Misty Law volcanic centre, and the small ones as representing the basic necks of North-west Ayrshire. Only we must remember that, while in Ayrshire we are dealing with the roots of ancient volcanoes, in Arizona the volcanoes are only recently extinct and still keep practically their original form, though atmospheric weathering has already set in, and has formed large gravel fans of volcanic material on the flat ground at the base of the large cones. If the simile be taken further, these fans can be likened to the so-called volcanic detritus and conglomerates which occur in Ayrshire between the volcanic rocks and the Carboniferous Limestone sediments. Only in Ayrshire these beds were deposited in sea water, though they may represent a resorting of pre-existing land detritus.

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Petrography of the Necks.[2]

Basaltic Tuffs.—These usually weather to a reddish-brown rubbly mass, from which it is difficult to obtain fresh material. The best specimens have been got from the interiors of spheroids, where the tuff is of a dark greenish-black colour. Occasionally large individual crystals of ferro-magnesian minerals occur, such as the rounded biotites from No. 20, and the augites and hornblendes from No. 17. Under the microscope the tuffs from all the necks which have been collected are of the same type (17652-3 and 17662-3), and consist of numerous fragments of various basalts, felsites, and sandstones. The basalt fragments are usually glassy and very amygdaloidal, and have occasionally been rounded into lapilli. The vesicles are filled with analcite and calcite. In (17674) and (17678) the basalts appear to be felspar-free, and are probably limburgitic. In (18443) they are mostly augite-rich, and of the Hillhouse type. The matrix is dark coloured and composed of finely comminuted basic lava, is often chloritised and calcitised, and contains a varying amount of quartz grains. Certain slides (17663, 17674, 18443) also contain small fragments of a brown highly refracting isotropic mineral, which is probably a spinel.

The following crystallographic and optical characters of the large ferro-magnesian minerals have been determined:—

Biotite.—The optic axial angle is large, 2 H being 20° 23′. The refractive index is 1·622 (β and γ), which is rather higher than usual.

Basaltic Hornblende.—The prismatic cleavages are well defined, as also are those of the clinopinacoid and clinodome.

Extinction, $c : \overset{\prime}{c} = 6°$.	(In the obtuse angle β.)	Refractive index, 1·6915 (β and γ).
Optical sign, —.		Pleochroism, b pale yellowish green. c greenish brown.

Augite (slightly titaniferous).—Prismatic cleavage on (110) at about 87°, also on (100) the orthopinacoid, and on (001) the basal pinacoid.

Extinction, $c : \overset{\prime}{c} = 44°$.	(In the obtuse angle β.)	Refractive index, 1·7067 (β and γ).
Optical sign, +.		Pleochroism, b pale purple.
Optic axial plane, (b) [010].		(Not very strong) c pale yellow.

[2] The slide numbers refer to the Geological Survey Collection.

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The refractive index in all cases has been obtained by the Schroeder van der Kolk method.

The Trachytic Tuffs.—The rocks of the Irish Law and Knockside Hills vents (Nos. 1 and 2) vary from coarse agglomerates to finely comminuted ashes and tuffs. (17644) shows a fine-grained brown rock with pink fragments up to ¼ inch across. The large fragments are mostly of soda trachyte, with porphyritic albite in a mass of oligoclase microlites. The matrix consists largely of the same material in a finely comminuted state, and in addition contains fragments of a glassy mugearitic basalt and a fair number of clastic quartz grains.

Basalt Blocks.—These vary in size from a few inches up to a foot or more across. They are of well-known Lower Carboniferous types, Markle, Jedburgh, and Dunsapie basalts, as well as mugearites, being common. They are usually decomposed, and often calcitised, silicified, or albitised.

Felsite Blocks.—These are of the same type as the felsite dykes and sills that cut the surrounding rocks. Slide (17488), from No. 9, is a pinkish grey rock, with small porphyritic alkali-felspar phenocrysts, which have uniform extinction, and seemingly are not perthitic. Small patches of quartz also occur, and the groundmass is a fine-grained granular mosaic of quartz and albite.

An interesting block was obtained from No. 17, and is a dark grey rock of fine crystalline character, with conspicuous small red garnets and white felspars. Under the microscope the rock (18444) is seen to consist of red garnet, a green pleochroic augite, labradorite felspar, and analcite. The garnet is surrounded by a wide kelyphitic border, which occasionally has wholly replaced the garnet, and now consists of chlorite. It differs from Rosenbusch's description of kelyphite in that it is in direct conjunction with augite (1910, p. 178). The augite is seldom well shaped, and occurs both as clear crystalline masses and as spongy aggregates, of which numerous cavities are filled with analcite. The felspar occurs in almost equal quantities with the augite, is allotriomorphic, and approximates to labradorite in composition. It is usually twinned, partially decomposed and analcitised. Analcite also occurs interstitially throughout the rock. The rock is difficult to place. It has

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some affinities with the eclogites, but the abundance of plagioclase felspar would remove it from that type. The rock is probably a xenolith of some moderately basic igneous rock which has suffered considerable metamorphism. The pyroxene and the general structure are similar to those presented by certain of the xenoliths found in the sapphire-bearing sill of the Nun's Pass, Carsaig, Island of Mull, and regarded as metamorphosed gabbro.

Basic Plugs.—The rock from the small intrusion at the south margin of No. 20 is a fine-grained dark grey compact basalt of the Hillhouse type. Under the microscope it (17468) is seen to consist of a few microporphyritic felspar crystals, idiomorphic augite, and olivine, set in a microlitic groundmass of minute crystals of felspar, augite, and olivine. The small isotropic brown mineral already mentioned as occurring in the basic tuffs is also present. The interstitial spaces are filled with analcite. The basalt portion of the plug in No. 1 is a pale brownish rock, with small pink felspar phenocrysts. Under the microscope it (19288) is found to be a microporphyritic partly-albitised Dunsapie basalt, in which the augite occurs fresh as slightly pleochroic light brownish-yellow phenocrysts, which are occasionally spongy. The olivine is represented by large pseudomorphs of a radial zeolite, with oblique extinction, which is probably stilbite. Some irregular grains of sphene are scattered through the zeolite. The felspar phenocrysts are usually spongy and sericitised in the interior, but have a clear margin. They are also occasionally slightly albitised, and probably represent an acid labradorite zoned to oligoclase. The groundmass is microlitic, and consists of small felspar laths, some similar to the felspar of the phenocrysts, and others consisting of oligoclase. The augite is granular, needles of apatite are abundant, and there is much interstitial chlorite.

The rock of No. 6 is a fine dark grey crystalline dolerite (17475), in which the olivine is partly fresh and microporphyritic. The groundmass is a granular aggregate of augite, labradorite, and iron ores.

The dolerite of No. 13 is a dark moderately fine-grained rock (18584), which is somewhat decomposed, and consists of zoned porphyritic titaniferous augite crystals, and fairly large pseudo-

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morphs after olivine in a relatively fine-grained groundmass of plagioclase, microlitic to micro-ophitic augite, small pseudomorphs after olivine, and a fair amount of chlorite.

Trachytic Plugs.—The trachytic portion of No. 1 is a fine-grained pale brownish rock (19287), and consists of small decomposed phenocrysts of soda-orthoclase, and a few small chloritic pseudomorphs, presumably after olivine. The groundmass consists of small square-ended albite laths, arranged with good fluxion structure. Iron ore is fairly abundant, and there is a little apatite. The rock appears to be one of those albite trachytes which contain olivine, and thus has affinities with marloesite (Thomas, 1911).

The soda trachyte of No. 2 is a reddish-brown compact rock, with small red-stained porphyritic felspars. Under the microscope (17643) the felspars are seen to be microperthitic anorthoclase. The groundmass consists of oligoclase-albite microlites, arranged with local fluxion structure; apatite is fairly abundant.

The rock from the small plug No. 3 is best described as a porphyritic orthophyric soda-trachyte. It varies in texture from an orthophyre (17660) to a good trachyte (17661). The phenocrysts are anorthoclase and albite in the first slide, and soda-orthoclase and soda-microcline in the second. The groundmass consists of short, sometimes square-ended, crystals of orthoclase and albite, with a fair quantity of interstitial quartz. In (17661) a few well-shaped phenocrysts after augite occur.

It will be seen from the above descriptions that the more acid rocks connected with the volcanic activity of the district are distinctly rich in soda.

My thanks are due to Dr. H. H. Thomas for the petrographic descriptions and help with that part of the work, and to the late Dr. C. T. Clough for valuable assistance during the course of the investigation.

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PROCEEDINGS OF THE GEOLOGICAL SOCIETY OF GLASGOW.

SESSION 1915-1916.

(Fifty-eighth Session.)

REPORT OF THE COUNCIL FOR 1914-1915.

[Submitted 11th November, 1915.]

The Council have again the pleasure of making their Annual Report upon the business of the previous session, the fifty-seventh of the Society's existence, and they have reason to think that upon the whole the progress attained has been satisfactory and the outlook for the future favourable, notwithstanding the fact that the interests of most people have been turned from purely scientific studies to the art of war.

At the commencement of session 1914-15 there were 147 Ordinary Members on the roll. During the year this was increased by 18 new Ordinary Members, bringing the total up to 165. During the same period the Society's membership was reduced by 11 resignations, and 2 members deceased, leaving 152 Ordinary Members on the roll of the Society at 30th September, 1915.

The meetings of the past session were fairly attended, though on the average not more than one-fourth of the total membership seemed to have been present on any one occasion. Numerous interesting and valuable papers were read and discussed and a large variety of specimens was brought forward for exhibition and remark. Among the former may be mentioned the opening address on "A Recent Visit to the Alaskan and Klondyke Goldfields," by Mr. H. M. Cadell; the retiring Presidential address on "The Tectonics of the Rocky Mountains and the Selkirks," by Dr. Horne; "Glacial Erosion in North Arran," by Dr. F. Mort; "The Age of Loch Long," by Prof. J. W. Gregory; "The Geology of the North Berwick Coast," by Mr. Alex. M'Lean; "The Igneous Rocks of Bute," by Mr. W. R. Smellie; "The Girvan Landslip" and "The Igneous Rocks of the East Kilsyth Hills," by Mr. J. V. Harrison; "Fossil Moulds and Bacteria," by Dr. Ellis; "The Annan Red Sandstone Series of Dumfriesshire," by Prof. J. W. Gregory and Dr. Horne; and "The Hurlet Sequence in North Lanarkshire," by Mr. P. Macnair.

The following members are engaged at present on active service, namely:—Messrs. John Andrew, Schoolhouse, Renton; Wm. M. Gale, Huntly Gardens, Glasgow; Percy B. Gilchrist, 16 Priory Road, London; J. G. Walker, Hill Park, Glasgow; and D. W. Fife, 11 Melrose Gardens, Glasgow.

Two members are at present with the Shackleton Antarctic Expedition,

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Mr. Alex. Stevens being with the Ross Sea Party, and Mr. James M. Wordie with the Weddell Sea Party.

The deceased members consisted of Mr. Robert S. Carmichael, auditor of the Glasgow & South-Western Railway, St. Enoch Station, who joined the Society in 1880, and Mr. David Stirling, 10 Cook Street, Glasgow, who joined in 1891; also Mr. A. B. Macdonald, late City Engineer, who had intimated his resignation some months ago. He joined the Society in 1884.

Amongst the Honorary Members we have to regret the death of Mr. Wm. Jolly, who joined the Society as an Ordinary Member in 1884. In the following year he was elected a Vice-President of the Society, and held office for the usual term. In 1904 he was elected an Honorary Member of the Society. Mr. Jolly was born in Arbroath in 1838 and received his early education in his native town, from which he passed to the Church of Scotland Normal School, Edinburgh. After holding several scholastic appointments in Ayrshire and Edinburgh he was made Inspector of Schools in 1869, and shortly afterwards was transferred to Inverness where he remained for fourteen years. During his stay in the north he helped to found the Banffshire Field Club and Scientific Society, and he took a great interest in all matters scientific, archæological, and social. His purely literary and educational work need not here be detailed as it has been referred to elsewhere. As far as I am aware his first geological paper was contributed to the Geological Society of Edinburgh in 1868, on "The Evidences of Glacier Action in Galloway." He also wrote the chapter on the Geology of Oban in Professor Blackie's "Altavona," in which work, written in the colloquial style, Mr. Jolly figures as "Hilarius," by which pseudonym he was usually addressed in Camp Siluria. He also wrote the article on Geology in that pioneer of literature for the masses, Chamber's "Information for the People." His only contribution to our *Transactions* was a paper published in 1885, entitled "The Joint Excursion of the Edinburgh and Glasgow Geological Societies to Ben Nevis and the Parallel Roads of Lochaber in July, 1885." This is the record of a long excursion of the Society into that district. Mr. Jolly was secretary of a committee of the British Association appointed to gather fossils in the remote parts of the North West Highlands, and a number of reports drawn up by him in connection with the work of this committee appeared for several years in their Annual Reports.

SOCIETY'S ROOMS, 207 BATH STREET, 14TH OCTOBER, 1915.

The first meeting of the fifty-eighth Session of the Geological Society of Glasgow was held here this evening—Professor J. W. GREGORY in the chair.

The Minutes of the last meeting were read and adopted.

The following were elected Ordinary Members:—Mr. P. E. Dollin, 24

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Watson Avenue, Rutherglen, proposed by Mr. J. Steel and Mr. H. R. J. Conacher.

Mr. Walter Weir, Calder Iron Works, Coatbridge, proposed by Mr. C. T. Clough and Mr. R. G. Carruthers.

Professor J. W. GREGORY then delivered his presidential address, the subject being "Geological Factors Affecting the Strategy of the War." [See *Transactions*, vol. xvi., pp. 1-33.]

J. W. GREGORY.

SOCIETY'S ROOMS, 207 BATH STREET, GLASGOW, 11TH NOVEMBER, 1915.

The second meeting of the fifty-eighth Session of the Geological Society of Glasgow was held here this evening—Professor J. W. GREGORY in the chair.

The Minutes of the last meeting were read and adopted.

Mr. Donald Patton, M.A., B.Sc., Manse Villa, Pollok Road, Shawlands, was elected as an Ordinary Member, being proposed by Mr. P. Macnair and Mr. H. R. J. Conacher.

Mr. PETER MACNAIR, *Joint Honorary Secretary*, read the Report of the Council for Session 1914-15.

The Financial Report for the past Session was submitted on behalf of Mr. E. H. Wight, *Honorary Treasurer*.

Mr. W. SINCLAIR, *Honorary Librarian*, reported on the work of the library during 1914-15.

Mr. JAMES STEEL moved, and Mr. Arch. A. Young seconded, that these reports be adopted, which was carried unanimously.

The following office-bearers were elected :—

Vice-President—Rev. C. A. Hall, F.R.M.S., proposed by Mr. J. Stark and Mr. D. Smith.

Members of Council—Mr. D. Chalmers, proposed by Mr. J. Stark and Mr. E. H. Wight; Mr. W. R. Smellie, M.A., B.Sc., proposed by Mr. J. V. Harrison and Mr. A. Scott; Mr. E. J. Edwards, M.Sc., proposed by Professor D. Burns and Mr. H. R. J. Conacher; Mr. G. W. Tyrrell, A.R.C.Sc., proposed by Mr. J. Neilson and Mr. D. Smith; Mr. A. Scott, M.A., B.Sc., proposed by Mr. J. V. Harrison and Mr. W. R. Smellie.

Mr. WISE moved that a vote of thanks be awarded to the retiring office-bearers, which was carried by acclamation.

Mr. JAMES STEEL exhibited the jaws of a Port Jackson shark, and pointed out that they showed the nature and arrangement of teeth in primitive fish, particularly the palatal teeth so familiar as fossils in the Carboniferous rocks.

Mr. ALEXANDER SCOTT, M.A., B.Sc., read a paper on "Primary Analcite and Analcitization." [See *Transactions*, vol. xvi., pp. 34-45.]

Professor J. W. GREGORY complimented the author on his paper, and said it was satisfactory to find that while there was ground for the views

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of both the British and Continental workers, the balance of truth lay with the British.

Mr. G. W. TYRRELL said that in addition to the evidence brought forward by Mr. Scott, the fact that analcite is such an important constituent (sometimes about 40 per cent.) of many rocks points to its being a primary ingredient, as such rocks, minus their analcite, would be too spongy in structure to resist the pressures to which they had undoubtedly been subjected. He also compared its mode of occurrence with that of quartz in a granite, and thought that the two were quite analogous.

Mr. P. MACNAIR, F.G.S., read a paper on "The Horizons of the Type Specimens of Dithyrocaris Tricornis and D. Testudinea." [See *Transactions*, vol. xvi., pp. 46-60.]

Mr. R. G. CARRUTHERS, H.M. Geological Survey, said that he quite agreed that these specimens must have come from a peculiar bed lying at the top of the Blackbyre Limestone at Arkleston, and congratulated Mr. Macnair on having settled a question that had been for so long a source of discussion.

R. W. DRON.

SOCIETY'S ROOMS, 207 BATH STREET, GLASGOW, 9th December, 1915.

The third meeting of the fifty-eight Session of the Geological Society of Glasgow was held here this evening—Mr. R. W. DRON in the chair.

The Minutes of the last meeting were read and adopted.

Mr. JOHN BALLANTYNE read a paper on "The Structure and Formation of Coal." He said that this subject had long been under investigation, and that it was now generally agreed that coal is fossilised wood, but many of the details of its formation remained to be cleared up. Within recent years the microscope had been brought to bear on the problem, and had thrown considerable light upon it, but there was still difference of opinion as to the mode of accumulation of the vegetable matter. After discussing the evidence Mr. Ballantyne gave it as his view that those coals which contain a high percentage of ash are probably derived from vegetable matter drifted by water until it became water-logged and sank in river or sea. He considered, however, that the majority of good coals had been derived from peat bogs, and not from a forest growth of timber. In support of this view he exhibited a large number of photomicrographs showing that the remnants of vegetable matter discernible in both materials were somewhat akin, being different stages in the same process. He surmised that bacterial action played a part in the transformation.

A series of microscope sections was also exhibited by means of the microprojector to demonstrate the different varieties of coal of various ages. In the discussion which followed, Dr. Ellis said that he did not quite follow what the lecturer had meant by bacterial action, as the only action of the kind which he could think of as likely to play a part would result in the production of hydrocarbon gases which would escape and

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lower the percentage of carbon in the mass, while raising the percentage of ash.

Mr. JAMES NEILSON exhibited specimens of copper ore from Gourock, native copper from Barrhead, musical sand from the Isle of Eigg which had lost its musical properties by keeping, and a curiously shaped stone from Glen Lyon, which had been variously regarded by different authorities as shaped by natural and human agencies. He also showed specimens of hornblende-diorite from Crois, Arrochar, and a number of lantern slides illustrating the scenery of the Arrochar district.

J. W. GREGORY.

SOCIETY'S ROOMS, 207 BATH STREET, GLASGOW, 13TH JANUARY, 1916.

The fourth meeting of the fifty-eighth Session of the Geological Society of Glasgow was held here this evening—Professor J. W. GREGORY in the chair.

The Minutes of the last meeting were read and adopted.

The following were elected Ordinary Members of the Society:—Miss J. B. Trench, M.A., B.Sc., 1 Springfield Terrace, Crossmyloof, proposed by Mr. W. R. Smellie and Mr. A. Scott; Mr. John B. Wingate, 208 St. Vincent Street, Glasgow, proposed by Mr. W. M'Creath and Mr. E. Hall Wight; Mr. L. Hawkes, B.Sc., 36 Blythswood Drive, Glasgow, proposed by Mr. W. R. Smellie and Mr. H. R. J. Conacher; Mr. Colin M. Leitch, B.Sc., 223 New City Road, Glasgow, proposed by Mr. W. R. Smellie and Mr. H. R. J. Conacher; and Mr. A. Sutherland, 12 Regent Park Terrace, Glasgow, proposed by Mr. Wm. Sinclair and Mr. P. Macnair.

Notice was given that at the next meeting it would be proposed that Mr. George F. Black, New York Public Library, New York, be elected a corresponding member of the Society.

Professor GREGORY announced that Mr. G. W. Tyrrell had been awarded the Murchison Fund by the Geological Society of London in recognition of the merit of his researches.

Mr. ALEX. SCOTT, M.A., B.Sc., read a paper on "The Physiography of Glen Lednock." [See *Transactions*, vol. xvi., pp. 61-74.]

Professor GREGORY complimented the author on his paper, and agreed with him that Glen Lednock was of great antiquity, and probably pre-glacial. He also pointed out that it was only by the study of these river valleys that it was possible to elucidate the history of Scotland during the long period between the Tertiary and Glacial times, as there were no deposits of that age in Scotland to contain a record. The study of this and similar glens also threw light on the question of whether movement was constantly proceeding on the line of the Highland boundary fault. The existence of a sudden drop in the beds of such glens points to there having been a sudden uplift of the country north of the fault in comparatively recent times.

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In reply the author stated that the apparent rejuvenation of these glens does point to an uplift, but it may be due to another cause. In Glen Turret, however, the burn is cutting rocks of Old Red Sandstone age on both sides of the fault, and therefore the pronounced fall in that glen supports Professor Gregory's suggestion. He agreed with Mr. Macnair that dykes have some connection with the direction of the gorges.

Mr. MACGREGOR, B.Sc., H.M. Geological Survey, read a paper on "An Ancient Shore Line." [See *Transactions*, vol. xvi., pp. 75-85.]

Professor GREGORY congratulated Mr. Macgregor on having solved a problem that had baffled so many authorities. The solution showed that Old Red Sandstone strata must have covered that district as recently as late Jurassic times.

J. W. GREGORY.

SOCIETY'S ROOMS, 207 BATH STREET, GLASGOW, 10TH FEBRUARY, 1916.

The fifth meeting of the fifty-eighth Session of the Geological Society of Glasgow was held here this evening—Professor J. W. Gregory, F.R.S., in the chair.

The Minutes of the last meeting were read and adopted.

Mr. George F. Black, New York Public Library, New York, U.S.A., was elected a Corresponding Member on the proposal of Mr. P. Macnair and Mr. H. R. J. Conacher.

Mr. LEONARD HAWKES, B.Sc., read a paper on "The Geology and Physiography of Iceland." After giving a description of the topographical features of the island, he said that, geologically, Iceland may be split into two formations, an older one of Tertiary age and a younger Post-Tertiary. The older formation is of the same age and nature as the Tertiary rocks of Skye, Mull, and Antrim, but whereas in the British Isles the volcanic activity ceased at the close of Tertiary time, in Iceland it has been continued down to the present day, and the study of the modern volcanoes and deserts of Iceland has furnished us with a key to the conditions under which the Tertiary igneous rocks of the North Atlantic region were built up.

There are three types of volcanoes in Iceland. First, the volcano of conical section, built up of layers of lava and ashes, of which Hecla is a type; this is the least important. Second, the very flat cone of small relative height, built up entirely of lavas which have flowed out from a centre; and third, a type of volcano peculiar to Iceland, in which the lava has welled forth out of fissures sometimes thirty miles long. The lava, being very fluid, inundates the country like a water-flood, and there is practically no accompanying fragmental deposit.

A description was given of a journey across the desert of Askja, Iceland's largest volcano. Travelling over the lava deserts is often very difficult. The compass is of little use on account of the large amount of iron in the

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lavas, and there is the dread of the volcanic ash storm. In the deserts on all sides stretches the black, stony sea, out of which the tuff volcanoes loom like islands, whilst there is no vegetation or sign of living thing. A description was then given of Askja, a large crater eighteen miles in circumference, and its probable history traced up to the time of the great eruption of 1875 when ash was carried over to Stockholm. It is possible to identify the minerals in the fragments carried over to Sweden.

Mr. P. MACNAIR exhibited specimens of the Hurlet Alum Shale Fauna from Charleston, Fife, and pointed out that the whole faunal association was identical with that of the West of Scotland. He also showed that this characteristic group of fossils could be traced from the borders of Lanarkshire and Edinburghshire through the Bathgate Hills far into the north-east of Fife, always occupying the same stratigraphical horizon.

CHARLES A. HALL.

SOCIETY'S ROOMS, 207 BATH STREET, GLASGOW, 9TH MARCH, 1916.

The sixth meeting of the fifty-eighth Session of the Geological Society of Glasgow was held here this evening—the Rev. C. A. HALL, F.R.M.S., *Vice-President*, in the chair.

The Minutes of the last meeting were read and adopted.

Mr. G W. TYRRELL referred to the death, early in the week, of Professor Judd, who had been an Honorary Member of the Society since 1883. He reviewed the work of Professor Judd, much of which related to Scotland, and moved that a letter be sent to his relatives expressing the Society's appreciation of his work for geology both as investigator and teacher, and their sense of the loss sustained by science through his death.

Mr. G. V. WILSON, H.M. Geological Survey, read a paper entitled "Preliminary Notes on the Volcanic Necks of North-West Ayrshire." [See *Transactions*, vol. xvi., pp. 86-99.]

Mr. TYRRELL remarked that the paper showed that considerable resemblances exist between the features in the district described and those found in the Cumbraes. Mr. Macnair pointed out that there is an ash bed in the Campsie and Carriden districts and elsewhere on approximately the same horizon as the Dalry Blackband Ironstone, and asked Mr. Wilson if he thought the two could be identified, but the latter thought it difficult to form a definite opinion on such a point when the only evidence was the character of the ash.

Mr. W. R. SMELLIE exhibited a large polished section of *Lepidodendron Wunschianum* from the volcanic beds at Laggan, Arran.

On behalf of Mr. J. V. HARRISON, a paper was read describing a section at Tormore, Arran, showing the junction of the two New Red Sandstone series of Arran.

JAMES NEILSON.

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SOCIETY'S ROOMS, 217 BATH STREET, GLASGOW, 13TH APRIL, 1916.

The seventh meeting of the fifty-eight Session of the Geological Society of Glasgow was held here this evening—Mr. JAMES NEILSON in the chair.

The Minutes of the last meeting were read and adopted.

Mr. ALEXANDER M'LEAN exhibited a number of large crystals of quartz, got in a granite quarry at Aberdeen and showing well-developed faces.

Mr. ALEXANDER M'LEAN read a paper entitled "Notes on the Age of the Human Race, based on Evidence found in Post-Pliocene Strata." He referred to the opinion held in certain quarters that the age of the human race was not many times greater than the sum of the classical and historical periods, and quoted many authorities to show that, so far from this being the case, the investigations carried out during the last half-century had produced evidence of a vastly greater antiquity. In the ancient river gravels, and in caves and on other sites, human relics had been found which gave clear evidence of a series of well-marked stages in the progress of the race from a state of extreme simplicity. A discussion ensued which emphasised the various speakers' views as to the great age of the race, it being pointed out that classical civilisation itself could claim an antiquity greater than is sometimes allotted for the passage of the race through the entire course of development.

Mr. H. R. J. CONACHER read a paper entitled "Notes on an Occurrence of Petrified Plant Remains in Lower Limestone Strata at Bridge of Weir." He said that in the strata immediately underlying the Blackhall Limestone in the banks of the Gryfe there was exposed a group of about half-a-dozen tree stumps. These showed the well-known external characters of the roots of Lepidodendron and Sigillaria, and, in addition, parts of the internal woody tissue. The main axis showed that a kind of "tap-root" had existed, and a series of slowly tapering ironstone cylinders, with calcite cores, which penetrate the embedding shale, no doubt represents the rootlets proceeding from the spreading roots. So far none of these rootlets have been found with any vestiges of internal structure preserved, but such may yet come to light. Relics of the aerial branches also occur, but these are in a state of preservation much less favourable for microscopic study. The tissues in the main roots, where these are in the best condition, have been preserved in calcareous material which permits the employment of high powers of magnification, and the structures are undeformed by pressure, but the aerial stems are preserved in iron-pyrites, the opaque crystals of which have obliterated the finer details. It would seem that the roots, embedded in the soft mud and readily accessible to the petrifying mineral solutions, had thus had their harder parts preserved from decay and been enabled to resist the pressure exerted by overlying deposits. The aerial branches, on the other hand, shaken from the dead trees, were already much decayed and deformed by pressure before the mineral solutions had the opportunity to act. A series of specimens from the locality was exhibited, including microscope sections shown by the aid of the micro-projector.

J. W. GREGORY.

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SOCIETY'S ROOMS, 207 BATH STREET, GLASGOW, 11th MAY, 1916.

The eighth meeting of the fifty-eighth Session of the Geological Society of Glasgow was held here this evening—Professor J. W. GREGORY in the chair.

The Minutes of last meeting were read and adopted.

Mr. MACNAIR exhibited a series of specimens got from the ancient bed of the Clyde in the course of digging the foundations of the new Dalmarnock Power Station. The specimens consisted of hazel nuts, twigs, and timber, and the epidermis of pearl mussels. The pearl mussels had lost all trace of the calcareous shell, through the action of percolating water, and only the chitinous epidermis remained, resembling dead leaves in brittleness and form. Mr. Macnair pointed out that the occurrence of such relics had been recorded about half a century ago in proximity to the present course of the Clyde, and there could be no doubt that they came from the same bed, which also contained human relics in the shape of dug-out canoes.

Professor J. W. GREGORY then read a paper on "The Auld Wives' Lifts: a Pseudo-Megalithic Tor."[1] He described the position of the well-known stones and referred to the traditional explanation of their origin, which ascribes them to a trial of strength between three witches of the district. For long the stones had been regarded as an example of a cromlech erected by the race which has dotted the country with megalithic structures. Careful examination, however, had shown that the group is purely the result of natural processes of denudation isolating a portion of the gritty sandstone of the district which had been dismembered, and the fragments thrown into their present attitude by slipping along joints and bedding-planes. It was shown that this could be proved by the fact of the existence, on the lines of fracture, of prominences corresponding with hollows on the opposite block.

Mr. LUDOVIC M'L. MANN pointed out that although the erection of the blocks could not be ascribed to man and the structure differed in some respects from the typical cromlech, there could be no doubt that it had been adopted by the early inhabitants of the district. He believed that the upper surface of the capstone had been levelled by the prehistoric process of "knapping," and had then been sculptured, the traces being quite evident to the trained eye. Other evidence also showed that the district had been one of special interest to the early inhabitants, and was now of importance to the archæologist.

JAMES NEILSON.

[1] *Scot. Geog. Mag.*, vol. xxxii., pp. 279-82, 1916.

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EXCURSIONS—1916.

To the Geological Department of the University and the Hunterian Museum on Saturday, 18th March. The party was conducted through the Museum by Professor J. W. Gregory and Mr. W. R. Smellie, and numerous interesting specimens, including the type-specimen of *Apractocleidus teretipes*, were exhibited. The Laboratory of the Geological Department was also visited, and the methods of slide-making and the uses of various instruments such as the Goniometer, the Sclerometer, the Westphal Balance and so forth were demonstrated.

To Dalry, on Saturday, 15th April—Mr. G. V. Wilson, conductor. The volcanic neck near Holmbyre was examined. The material of the neck is a dark grey ash containing abundant crystals of biotite, fragments of various types of basalts and specimens of *Euphemus* and brachiopods such as *Productus*. The sections of the Upper and Lower Limestones on the Caaf Water were also visited.

To the Kames of Carstairs, on Monday, 24th April (Spring Holiday)—Professor J. W. Gregory, conductor. The party proceeded from Cleghorn to Stonebyres, where the pre-glacial valley of the Mouse Water was indicated, and then walked along the Kames to Carstairs. Sections, showing fluvio-glacial gravel and sand, were examined and the superposition of the Kames on the boulder clay was pointed out.

To Bridge of Weir, on Saturday, 13th May—Mr. H. R. J. Conacher, conductor. The general structure of the district was explained by the leader, and then a visit was paid to a glacial pit north-east of the station, where Mr. Ludovic Mann discussed the probable origin of the gravels and their points of archæological interest. The sections of volcanic rocks of Calciferous Sandstone age and the sediments of the Lower Limestone series, exposed in the Gryfe as far down as Crosslee, were afterwards examined and their leading features indicated.

To Dunfermline, on 23rd May (King's Birthday)—Messrs. R. Dunlop and P. Macnair, conductors. The party proceeded from Dunfermline Station to Woodmill for the purpose of examining the outcrop of highly fossiliferous shales which have been described by Mr. Dunlop (*Transactions*, vol. xv., p. 167, 1915). The party then visited the fine section in the Lower Limestone series exposed at Charleston and Mr. Macnair explained his correlation of the different strata with the Hurlet sequence in the West of Scotland.

To Gourock, on Saturday, 3rd June—Messrs. P. A. Leitch and J. L. Begg, conductors. Craigmushet Quarry was first visited and the keratophyric rocks noted, a number of minerals, including fluorspar, barytes, quartz, and tourmaline, being collected from the geodes. The section westwards along the shore, comprising Calciferous Sandstone sediments and Old Red Sandstone conglomerate, was then examined. Two volcanic necks near the Cloch were pointed out and also a fresh basalt of the Markle type in the quarry north of Lunderston Bay.

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To the White Loch, on Saturday, 27th June—Dr. A. Scott, conductor. The dependence of the topography of the district on the underlying rocks was first indicated and then the party traversed the sequence of Calciferous Sandstone lavas from Patterton to the White Loch. The volcanic rocks seen included basalts of various types as well as more acid mugearitic and trachytic rocks. The basaltic plug of Duncarnock was examined and also the series of lavas south-east of Neilston.

To the Auld Wives' Lifts, on Saturday, 14th October—Professor J. W. Gregory, conductor. The party proceeded from Milngavie to the Auld Wives' Lifts, where Professor Gregory pointed out the evidence in favour of the view that the "tor" had been formed by the weathering, *in situ*, of a block of the local sandstone.

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ABSTRACT

OF THE

TREASURER'S ACCOUNTS.

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ABSTRACT OF THE TREASURER'S ACCOUNTS FOR THE YEAR ENDED 30TH SEPTEMBER, 1915.

CASH ACCOUNT.

RECEIPTS.

To Subscriptions:—		
Ordinary Members (including 13 new Members)—135 at 10/, ...	£67 10 0	
Do. (including 1 New Member)—3 at 7/6, ...	1 2 6	
Do. Arrears—2 at 10/, ...	1 0 0	
Associates—12 at 2/6, ...	1 10 0	
Life Member, ...	5 5 0	
		£76 7 6
,, *Transactions*:—		
Sales per Hon. Librarian, ...	£2 9 7	
Do. per John Smith and Son (Glasgow), Ltd.,	3 18 9	
Mitchell Library for 40 copies of *Transactions*, Vol. XV., Part 1, .. £2 11 11		
Do. Vol. XV., Part 2, .. 4 0 10		
	6 12 9	
Advertising on Cover, ...	1 10 0	
		14 11 1
,, Donation from Dr. Gregory to meet estimated cost of publishing "Loch Long" Paper, ...		6 8 9
,, Interest on Funds, ...		5 7 10
,, Do. Mr. Cowie's Donation, ...		3 8 3
,, Balance due Hon. Treasurer at close of Accounts,	£17 1 1	
Less Cash on hand—Accrued Interest on Mr. Cowie's Donation, ...	1 13 1	
		15 8 0
		£121 11 5

EXPENDITURE.

By Balance due Hon. Treasurer, 30th Sept., 1914,	£10 5 11	
Less Cash on Hand—Accrued Interest on Mr. Cowie's Donation, ...	1 15 4	
		£8 10 7
,, *Transactions*—		
Printing and Publishing Vol. XV., Part 2, including cost of illustrations and Author's Copies of Papers, ...	£72 12 0	
Postages and Outlays, ...	2 1 10	
	£74 13 10	
Less Receipts from Authors for extra copies of Papers, ...	13 1 1	
		61 12 9
,, Library:—		
New Books, Bookbinding, Maps and Magazines, ...	£2 4 0	
Librarian's Outlays, ...	0 16 0	
Cost of New Bookcases, ...	7 14 10	
		10 14 10
,, Expenses re Micro-Projector, ...	.. ..	1 19 9
,, Administration:—		
Printing and Postage of Cards, Excursion Booklets, and Advertising, ...	£12 13 11	
Rent, Insurance, and Attendance, ...	12 0 6	
Disbursements by Hon. Secretaries, Postages, Stationery, and Petty Expenses, ...	5 9 7	
Lantern Expenses, ...	2 17 0	
		33 1 0
,, Subscription to Marine Biological Association, 1915, ..		1 1 0
,, ,, to Palæontographical Society, 1915, ...		1 1 0
,, Mr. Cowie's Donation:—		
Glasgow University, Interest to Martinmas, 1914, ...	£1 15 3	
Royal Technical College, Interest to Martinmas, 1914, ...	1 15 3	
		3 10 6
		£121 11 5

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ABSTRACT OF THE TREASURER'S ACCOUNTS FOR THE YEAR, ENDED 30TH SEPTEMBER, 1916.

LIFE SUBSCRIPTION ACCOUNT.

Sept. 30, 1915.—To Balance to Credit,	£187	15	0	Sept. 30, 1914.—By Balance from last Account,	£182	10	0
				Sept. 30, 1915.— ,, New Subscription,	5	5	0
	£187	15	0		£187	15	0

Mr. CHARLES R. COWIE'S DONATION.

Sept. 30, 1914.—To Glasgow University, one-half of Interest to Martinmas, 1914,	£1	15	3	Sept. 30, 1914.—By Balance from last Account,	£101	15	4
,, The Royal Technical College, Glasgow, one half of Interest to do.,	1	15	3	Sept. 30, 1915.— ,, One year's interest to Whitsunday, 1915,	3	8	3
Balance to Credit,	101	13	1				
	£105	3	7		£105	3	7

BALANCE SHEET.

To Life Subscription Account,			£187	15	0	By Invested with Campbeltown Corporation under Mortgage at 3½ per cent.,			£170	0	0
,, Mr. Charles R. Cowie's Donation and accrued Interest,			101	13	1	,, Property—Books in the Library,	£440	0	0		
,, Balance due Treasurer on Cash Account,	£17	1	1			Furniture, Bookcases, Microscope, &c.,	60	0	0		
Less Cash on hand—Accrued Interest on Mr. Cowie's Donation,	1	13	1							500	0	0
				15	8	,, Mr. Charles R. Cowie's Donation—Invested with Campbeltown Corporation under Mortgage at 3¾ per cent.,	£100	0	0		
,, Capital Account,*				466	17	,, Interest accrued to Whitsunday, 1915,	1	13	1		
										101	13	1
			£771	13	1				£771	13	1

* NOTE.—Subject to cost of publishing *Transactions*.

GLASGOW, *6th November*, 1915.—Examined, compared with relative Vouchers and Securities, and found correct, the balance in Treasurer's hands, accrued interest on Mr. Charles R. Cowie's Donation, being One Pound Thirteen Shillings and One Penny, and the Balance due Treasurer on Cash Account, Seventeen Pounds One Shilling and One Penny.

ARCH. MACINTYRE,
ALEXANDER M'LEAN. } *Auditors.*

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TRANSACTIONS

OF THE

GEOLOGICAL SOCIETY OF GLASGOW.

No. VII.—The Geology of Phosphates and their Bearing on the Conservation of Mineral Resources. By Professor J. W. Gregory, D.Sc., F.R.S.

[Presidential Address, delivered 9th November, 1916.]

(Issued separately, 21st June, 1917.)

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1. The Use of Phosphate as Fertiliser.

"No phosphorus, no thought," declares a famous German epigram which expresses the belief that some of the physical reactions in the brain are controlled by phosphorus. The epigram is certainly true in a broader sense, for without phosphorus we should be without the food plants necessary to our existence. A crop of wheat of 30 bushels to the acre removes 14·3 lbs. of phosphoric acid (P_2O_5) in the grain and 8·4 lbs. in the straw; a crop of red clover of 2 tons per acre extracts 25 lbs. of phosphoric acid per acre, and 22 tons per acre of mangels use up 49 lbs. of phosphoric acid per acre. Hence soil loses its fertility unless the phosphorus available as plant food be restored by a fertiliser or by weathering rendering soluble that in the rock fragments. That phosphorus is an essential constituent of organic bodies was gradually proved after Gahn, in 1769, found it in bone and Scheele, in 1795, discovered how to extract it out of bone ash. The use of ground bones as a manure was introduced early in the nineteenth century; but their action was misunderstood. They contain 20 per cent. of phosphoric acid; nevertheless their manurial value was attributed to their 2 per cent. of gelatinous material. Thus Wyatt (1892, p. 18) quotes from a journal of 1830 that, as phosphate in bones is indestructible, it cannot serve as a manure; and he also records a later opinion, that as bones contain merely 2 per cent. of gelatine, and "derive their fertilising power from this substance only, they may be considered as having no value as manure." The Chinese were better informed; they had used bones as manure from time immemorial, and as they burnt the bones they clearly knew that the value was in the mineral matter present in the ash, and not in the gelatine. This conclusion was not fully accepted in Europe until 1843, when experiments by the Duke of Richmond proved that bones from which the gelatine had been removed were equal in fertilising power to fresh bones. That the phosphoric acid was the useful constituent was confirmed by the demonstration that on a soil from which the phosphorus had been removed plants would not grow until phosphate of lime was added. A practical proof on a

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great scale has been supplied by Australia, whose soils differ from those of the rest of the world in the distribution of phosphorus. As a general rule, phosphorus is concentrated in the soil, and the subsoil contains less. Thus in a collection of 220 soil analyses the phosphoric acid in the soil exceeds that in the subsoil by 16 to 13 (Gregory, 1915, p. 243). In Australia the soils are low in phosphate, and have not been enriched at the expense of the subsoil. The most plausible explanation of this condition has been suggested by Professor Cherry, of Melbourne; he attributes it to the poverty of Australia in the small mammals which in most countries continually deposit phosphorus on the surface in their excrement and bones. In some parts of Australia large tracts of fine, light soil were absolutely barren. Their sterility was due to the absence of phosphorus, and by its addition wide districts of obstructive desert were converted into productive wheat farms. So Emerson's vision of "agricultural chemistry, coolly exposing the nonsense of our spendthrift agriculture and ruinous expense of manures, and offering, by means of a teaspoonful of artificial guano, to turn a sandbank into corn" (Emerson, Complete Works, i., 1883, p. 360), was not without foundation, though it imagined a manure more powerful than any yet placed on the market.

The discovery of the great agricultural value of the phosphorus in ground bones led to the search for a more abundant supply. The mineral phosphates were at first regarded as useless, as they are practically insoluble; so their phosphorus is useless to plants. In south-western France the phosphatic masses that had weathered out of limestones were used to build walls, owing to their special durability, just as on the Somme rich phosphatic sand was ignorantly made into bricks. In his report to the British Association on the state of organic chemistry, Liebig, in 1840, recommended that to render bones more soluble they should be ground to powder and treated with sulphuric acid. This process had been independently adopted by Sir Gilbert Lawes. Whether Liebig or Lawes was the first discoverer of this process is disputed; but Lawes was the first to put it into practice, for he had made soluble superphosphate and used it on a large scale on his farm at Rothamsted in 1840.

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(See Warington in Hall, 1905, p. xxiii.). He, moreover, discovered that the mineral phosphates could be similarly utilised. He patented the process in 1842, established works at Deptford, and later at Barking, and thus gave England its long start as the first home of the superphosphate industry.

Lawes' work led to the search for larger supplies of raw phosphate. Buckland (1829, p. 234) described a phosphate nodule from Southwold, in Suffolk; and the commercial importance of the phosphates in that county was announced in 1845 by Professor Henslow in a paper to the British Association at Cambridge, of which a brief abstract was published in its reports (Henslow, 1846, pp. 51-52). He called attention to the occurrence in the Red Crag at Felixstowe of phosphatic nodules, the so-called coprolites, containing 56 per cent. of phosphate of lime, of similar nodules in the London Clay at Euston, and of nodules which contain 61 per cent. of earthy phosphate and 24 per cent. of carbonate of lime, which extend in a layer over many square miles in Cambridgeshire. It was from this Cambridge Greensand that the largest supplies of British phosphate have been obtained. The optimistic Liebig declared that England had, in such deposits, a mineral equal in value to her coalfields.

The discovery how to utilise mineral phosphates led to a world-wide search for them, and they have been found in practically all countries of the world and in rocks of all ages. The quantity is, however, usually so small or the quality so poor that comparatively few of the known occurrences are worked. The phosphate mines in England, Germany, and Canada have all closed. The following lists show the distribution and relative quantities of the chief present supplies of rock phosphate. It includes all countries which, in 1913, yielded over 10,000 tons and a few of the smaller contributors:—

	Metric Tons.
United States,	3,161,156
Tunis,	2,284,678
Algeria,	461,030
France,	335,000
Ocean and Nauru Islands,	300,000 (1912)
Belgium,	219,420 *
Christmas Island,	152,405

* The Belgium phosphate is a low grade phosphatic chalk, and the output is officially returned in cubic metres, which are usually taken as 1 ton = 2 cubic metres (*e.g.*, Aguillon, 1909, p. 438).

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	Metric Tons.
Egypt,	101,311
Pelew Islands (Angaur),	90,000
Makatea,	82,000
Russia,	25,000
Japan,	19,047
French Guiana,	7,014 (1912)
South Australia,	6,049
Sweden,	5,317 (1907)
Spain,	3,548
Dutch West Indies,	1,850
Norway,	757
Canada,	391 †

In 1913 the world's produce of phosphate rock was 6,888,000 tons; the United States produced 3,161,156 tons, of which 40 per cent. was exported to the superphosphate factories of Europe.

The war has deplorably reduced the usefulness of the phosphate industry. In 1915 America produced only 1,800,000 tons of raw phosphate, or over 1,250,000 tons less than in 1913. This fall is owing to the closing of the Continental factories, limited transport, and the diversion of sulphuric acid from manure to munitions. The North African mines have decreased their yield owing to the stoppage of their exports to Germany. In addition to natural phosphate, over 4,000,000 tons of basic slag are annually produced in Europe (more than half of the total in Germany), and used as phosphatic fertiliser. Its use in this country is hampered by the unsatisfactory citric acid test.

The importance of the phosphate industry may be illustrated by the fact that at the outbreak of war seven fertiliser periodicals were published in Europe—two in France, two in Germany, one in Belgium, one in Holland, and one in London. What has happened to the German papers I do not know, but the last number of the last of the remaining five was published in London during August, 1916, with the statement that the editor and the rest of his staff had been called up for military service.

2. The Chemical Constitution of Phosphates.

Phosphorus occurs in bones and the chief mineral phosphates in the form of tricalcium phosphate ($Ca_3P_2O_8$, or 3 CaO,

† This is produced as a by-product in mica mining.

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P_2O_5), in which there is one molecule of phosphoric acid to three molecules of lime. This material is insoluble; but treatment with sulphuric acid converts it into monocalcium phosphate ($CaH_4P_2O_8$). In this each molecule of phosphoric acid is combined with only one of lime; hence it is known as superphosphate, and as it is readily soluble in water, is immediately available as a plant food. Hence occurs the apparent anomaly that a soil which contains 3000 lbs. per acre of phosphate may yield only a very small crop of Swedes; yet, after the addition of only 60 lbs. of superphosphate, it may produce a very good crop. The plants can at once use the phosphoric acid in the superphosphate, while that in the soil is only rendered slowly available by the dilatory process of weathering.

Another lime phosphate is known as dibasic or bibasic phosphate, $Ca_2H_2(PO_4)_2$. It is insoluble in pure water, but is soluble in acids, even in the weak acids formed in a soil by plant decay. It is thus a useful manure. The phosphate in basic slag, which since 1885 has been largely used as a fertiliser, is either a tetracalcium phosphate with the formula $Ca_4P_2O_9$, *i.e.*, $Ca_3(PO_4)_2$, CaO, or is a complex double phosphate and silicate of lime. It is soluble in weak acids, and is therefore available as manure.

3. The Phosphatic Mineral Species.

The mineral species which contain phosphate as an essential element are very numerous. Phillips (1893) has catalogued those containing over 1 per cent., and his list includes 141 species. In addition to these mineral species, there are many phosphatic minerals of indefinite composition and structure to which names have been assigned, such as floridite given by Cox to the botryoidal rock phosphate of Florida, the cooperite of Morfitt for the phosphate of Navassa, and the same author's gibbsite for that of Alta Vela; the podolite of Chirvinski from the veins of Western Russia; the nauruite of Elschner for the agate-like phosphate of Nauru; and the complex quercyite from South-Western France, which has been explained after a refined investigation by Professor Lacroix (1910).

Among the phosphates which occur as rock constituents are

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xenotime, the phosphate of yttrium (YPO_4); monazite, the chief source of the material used for gas mantles, and a phosphate of cerium, lanthanum and didymium; triphylite and its allied species, which are double phosphates of various elements, including lithium, iron, manganese, sodium, and beryllium; pyromorphite, a phospho-chloride of lead; the wagnerite group, including various phosphates of magnesium, calcium, iron, and manganese; amblygonite, a fluo-phosphate of aluminium and lithium; libethenite and pseudo-malachite are hydrous phosphates of copper. The ornamental stone lazulite is a complex hydrous ferruginous phosphate. A massive variety of wavellite, the beautiful hydrous phosphate of alumina, is being worked for fertiliser in Victoria, and has been mined in Connetable Island, off French Guiana. The gem turquoise is a copper-stained hydrous phosphate of alumina. Vivianite, the common blue earth, is a hydrous phosphate of iron, of which strengite and koninckite are less well known species. There are numerous hydrous and aluminous phosphates, and many soluble phosphates, such as struvite, a hydrous phosphate of ammonia and magnesia, are found in guano deposits.

These species all either occur in small quantities or are secondary minerals formed by infiltration of phosphoric acid solutions. Even the phosphates which are usually classified as primary constituents of igneous rock, such as the minerals of the triphylite and wagnerite groups and amblygonite, generally occur in pegmatites or in granites which are shown by the associated tourmaline to have undergone pneumatolytic action. These species are, however, so relatively scarce that the all-important primary source of phosphorus is the mineral apatite.

The ordinary formula for apatite, which is due to Gustav Rose, represents it as a tricalcic phosphate of lime combined with calcium chloride in chlor-apatite, or with calcium fluoride in fluor-apatite. Varieties, however, occur which contain neither chlorine nor fluorine. Their existence is generally ignored, and has been disputed;* but it has been clearly established by the work of Voelcker (1883). He showed by analyses of Kragerö apatite that both fluoride and chloride may be

* Rammelsberg thought that the absence of the calcium chloride fluoride was due to alteration.

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replaced by lime. Laspeyres, at the instance of Rammelsberg, repeated these analyses, and confirmed Voelcker's conclusion. Subsequently Carnot found that the apatite of Mount Greiner, in the Tyrol, and of Mount Golling, in Styria, have less calcium fluoride and calcium chloride than are required by the accepted formula. Instead of 3·83 per cent. of fluorine there is only ·29 per cent. in the apatite of Mount Greiner; and only ·46 per cent. instead of 3·92 per cent. in that of Mount Golling (Carnot, 1896, No. 1, pp. 148-150). The phosphorite of Bouzouls in Aveyron, has only traces of calcium fluoride and calcium chloride (Carnot, 1896, No. 2, p. 154).

Carnot in the same paper gives a series of analyses of Algerian phosphates (*ibid.*, pp. 160-163) which have only traces of fluorine, and phosphorites of the Gand (*ibid.*, p. 159) which are without fluorine. Carnot argued that the Quercy phosphorites cannot be due to ascending waters because of their variability in fluorine, which he says is explicable if the phosphoric acid came from above.

The presence of lime-apatite appears to be now generally accepted, and A. F. Rogers (1912, p. 475) has founded for it the species, which he appropriately called voelckerite.

Apatite occurs in igneous rocks in tiny six-sided prisms, often terminated by pyramids. It is recognised in microscopic sections of rocks by its low double refraction and high refractive index. It was produced artificially by Daubrée (1851) by passing phosphorus trichloride over red-hot lime, and the apatite and other phosphates in pegmatites are probably due to some such process. The apatite of ordinary igneous rocks was probably formed by reactions similar to those used by Nacken (1912, p. 545) when making artificial apatite by fusion.

The apatite in igneous rocks always appears fresh and undecomposed. It is soluble in strong acids, but is only slowly attacked by water and carbonic acid; and it is therefore one of the very last minerals to fall a victim to weathering.

According to Comey (Dictionary of Solubilities), one litre of cold water will in seven days dissolve 79 milligrams of freshly precipitated tricalcic phosphate; *i.e.*, one pint will dissolve slightly over half a grain. Water containing carbon dioxide

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has a much stronger action, and, amongst other evidence that might be cited, R. Müller (1877, pp. 35-36) has shown that apatite is decomposed by carbonated water, and both the lime and phosphoric acid are dissolved.

In the breaking up of an igneous rock the apatite is probably mainly removed mechanically; but being moderately soft, and having two cleavages, it is soon ground into fine particles; and its minute subdivision facilitates its widespread distribution and solution.

Ordinary rock phosphate is not a simple mineral or mineral species, as owing to solution and redeposition it is often traversed by veins of various lime phosphates. Amongst them are—

Collophanite, amorphous. Regarded by Sandberger, from study of Sombrero material, as a mixture of carbonate of lime and tricalcic phosphate. According to Lacroix it is a mineral species with the composition—

$$\begin{cases} x\ Ca_3P_2O_8, yCaCO_3, zH_2O. \\ x\ CaF_2, Ca_8P_6O_{24}, yCaCO_3, zH_2O. \end{cases}$$

Dahllite, $2Ca_3P_2O_8, CaCO_3, \frac{1}{2}H_2O$.

Francolite, $CaF_2, Ca_8P_6O_{24}, CaCO_3, H_2O$.

Staffelite, a fibrous form of Francolite.

Quercyite, an intimate mixture of dahllite or staffelite with collophanite—

Var. α = negative.
Var. β = positive.

4. The Primary Igneous Phosphates.

In spite of the relative insolubility of apatite there can be no doubt that the ultimate source of practically all our phosphorus is the apatite of igneous rocks. According to F. W. Clarke (1911, pp. 27, 32, 398), the amount of apatite in the igneous rocks is ·6 per cent., or 6 parts in 1000; the average of 1025 analyses of igneous rocks gives ·26 per cent. of P_2O_5, or ·11 of phosphorus. The amount in sedimentary rocks is nearly as much. From the igneous rocks the phosphoric acid is carried to the sea, where it is present in the minute quantity of ·005 per cent., or 1 part in 20,000, of the water, or ·18 per cent.

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of the sea salts. It is removed from this water by various organisms, and thanks to them it is concentrated in beds rich enough to be of use to man. The geology of phosphorus is the story of its segregation from the widely diffused apatite of the igneous rocks into the rich beds and veins which are the raw material of the phosphate industry.

The primary igneous phosphates are seldom of direct commercial value except, as with monazite, for their other constituents. In Canada and Norway some pegmatite veins with apatite have been worked for phosphate. Those who hold that the great iron ore mass of Kirunavaara, in Swedish Lapland, is of igneous origin would hold that its apatite and that at Gellivara are also of igneous origin; and, if so, the basic slag made from those ores would owe its phosphorus directly to an igneous apatite.

In Canada the chief occurrences of apatite were in veins and pockets in granite and gneiss on the Lièvre River, a tributary to the Ottawa River at Ottawa, and also in the Brockville district to the north-east of Lake Ontario. The output was greatest, 32,000 tons, in 1890, and it has fallen to 167 tons in 1912, which were obtained as a by-product of the mica mines (Economic Minerals and Mining Industries of Canada, Department of Mines, Ottawa, 1914, pp. 50, 51) at Buckingham, Quebec. The Lièvre River apatite was probably formed mainly by hot ascending phosphoric acid.

The typical Canadian apatite occurred with segregations of pyroxenite in gneiss. The apatite was in pockets, which were worked by subterranean mining. They were mixed with silicates, and the material could only be brought to a grade rich enough to repay transport by hand-picking. According to Wyatt, the mines were generally worked at a loss. The working of this apatite is one of the instances of a mineral being worked too early. If it had been left till the country had been settled, transport was cheaper, and it could have been treated in local factories and used in the district, it might have been worked at a profit.

Some of the Canadian phosphate may belong to a different category from the igneous segregations, for some of it is in beds of limestone, through which, according to Wyatt, the

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phosphate is widely and evenly distributed. It is possible that these phosphates are due to the alteration of a granular phosphatic limestone.

A second important group of phosphates which may be of primary origin are the vein phosphates of Estremadura, in Spain. They occur as vertical veins of apatite in clay slate, near an intrusion of granite which has altered the slate to staurolite schist. According to an analysis quoted by Naranjo y Garza (1860, p. 161), the composition of this apatite is as follows:—

Phosphoric Acid,	40·12
Lime (CaO),	53·50
Hydrochloric Acid,	0·06
Hydrofluoric Acid,	2·27
Silica and Clay,	3·10
Ferric Oxide,	0·61
Loss,	0·79
	100·45

This apatite was most probably formed by ascending solutions which were connected with the granitic intrusion. Carnot, for example (1896, No. 2, p. 143), assigns to it a hydrothermal origin.

The Canadian and Scandinavian apatites are pre-Cambrian, and to the same age belong the nelsonites of Virginia. They are (Watson, 1914, pp. 398, 399; Watson and Taber, 1913) holocrystalline dyke-like sheets or segregations composed of apatite and either ilmenite or rutile. They occur in the margin of a syenite intrusion or in the gneiss beside it. These sheets are described as 2000 feet long by 65 feet wide; yet, in spite of their size, it is clear that they cannot pay to work unless the titanium also can be used. The composition of the nelsonite, according to one analysis, is—

SiO_2,	0·70
TiO_2,	42·84
Fe_2O_3,	11·12
FeO,	27·93
MnO,	·18
MgO,	·72
CaO,	8·34
P_2O_5,	6·89
Cl,	·01
F,	·21
H_2O,	·73
	99·67

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5. Organic Phosphates.

The main phosphates of commercial value are of secondary origin, and due to organic concentration. The phosphoric acid in sea water is excessively dilute; it is probably most abundant off the mouths of rivers which drain areas of igneous rocks that are especially rich in apatite. The phosphorus is concentrated by various processes, which may be confined to the sea or completed on land. The first process is the conversion of the dead shells of small organisms from carbonate of lime into phosphate of lime by the action of phosphoric acid. These altered shells fall upon the sea floor, and though their proportion is small they are stronger and less soluble than the unaltered calcareous shells. Off-shore currents sweep the lighter calcareous material seaward, while the harder phosphatic particles are left behind. They thus accumulate as beds of phosphatic chalk or limestone. The phosphatic grains thus formed are supplemented by material due to a second process—the secretion of phosphoric acid by living organisms. Most crustacea, the brachiopod *lingula*, and some other animals, have shells composed of phosphate of lime, and the teeth and bones of vertebrates are also largely phosphatic.

The phosphatic materials formed by these two processes accumulate as widespread layers on the sea floor. Part of them may be redissolved and redeposited, and thus give rise to beds of phosphatic nodules, such as the Cambridge Greensand.

(*a*) Phosphatic Concretions.

A third variety of marine phosphates consists of deep-sea phosphatic nodules. Their formation has been explained by Sir John Murray and Renard of Ghent (Murray and Renard, 1891, pp. 391, &c.), who attributed them to the concentration of phosphate from decomposing marine organisms. Phosphate of lime is proved by the Challenger analyses to occur in considerable quantities in some deep-sea deposits; thus the red clay at Station 276 (*ibid.*, p. 431) contained 3·44 per cent. of calcium phosphate; globigerina ooze from Station 64 (*ibid.*, p. 440) had 2·80 per cent.; and pteropod ooze from Station 22 (*ibid.*, p. 447) had 2·41 per cent. The bones of

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various marine mammals found on the sea floor contain both phosphate and fluorine. Thus a piece of whalebone (*ibid.*, p. 492) contained 60 per cent. of phosphate of lime and ·41 per cent. of fluorine. Some of the disseminated deep-sea phosphate is collected and deposited in concretionary nodules, which are sometimes 2½ inches in diameter, and are abundant in some places.

As Murray and Renard pointed out, the phosphate of lime is often deposited colloidally like hydrated silica. Hence phosphates are deposited in nodules, or as a cement between shells and sand grains, or as a paste filling cavities in shells or rock fragments. The Challenger Report (Plate xx.) gives excellent illustrations of glauconitic sand cemented by phosphate, of foraminifera in which the shells have been altered into phosphate, and of material in which the phosphatisation is so complete that the organic structures have been completely obliterated by the concretionary phosphate.

The formation of nodules of amorphous phosphate also occurs in shallow seas; thus in the Cambridge Phosphate bed, which was a shore formation, the phosphatic material was deposited as a gelatinous or amorphous phosphate in the cavities of the shells or corals. The original skeleton remained as carbonate of lime during the deposition of the phosphate, and the carbonate was subsequently removed in solution. Sometimes, moreover, the material has been deposited around inorganic grains, and may act as a cement; thus some of the Russian Cretaceous phosphates consist of a sandstone with the grains held together by a phosphatic cement.

(*b*) Guano Deposits.

The formation of guano is a process of phosphatic concentration which is completed on land. It begins in the sea by various animals feeding on smaller organisms and storing up their phosphate. These animals are eaten by others which concentrate the phosphate still further, and themselves fall victims to fish that are devoured in their turn by sea birds. Owing to the richness of fish in uric acid fish-eating birds are very gluttonous. A bird weighing 6 lbs., according to Elschner (1915), devours 3½ lbs. of fish at a meal, and he also reports

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that one bird produces annually from 25 to 50 lbs. of excrement (1913, p. 10). According to Dr. H. O. Forbes, the guano-producing birds off the Peruvian coast each daily swallows 8 to 10 lbs. of fish. If the human race consumed its weight in food every two days the most alarmist predictions of the Malthusians would soon be verified; but with the adaptability of Nature the very gluttony of the birds helps to save man from famine. The fish-eating birds resort for safety during the nesting season to small tropical islands, where they live in vast flocks. The accumulations of their excrement form the valuable manure guano. The name comes from the Peruvian "huanu" for "dung." It was adopted in Spanish as "huano," and altered to guano.

Though fish-eating birds are distributed throughout all the seas guano is practically limited to small tropical islands off the western coasts of South America, South Africa, and Australia. The main supply is obtained from the guano islands of South America, which extend for about 1000 miles along the coast of Peru and Northern Chile. Most of it originally came from the Chincha Islands, but in recent years the chief supplies have been derived from Pabellon de Pica, Punta de Lobos, and the Huanillos, near Iquique. The guano beds are from 50 to 60 feet in thickness. The most important constituents in fresh guano are the soluble nitrogenous salts, such as ammonium oxalate and ammonium urate. The impurities include carbonate of lime, magnesia, alumina, gypsum, and sand.

Guano is typically loose and soft, and so can be easily dug; but the percolation of water renders it granular or oolitic, and frequently laminated. The cavities are floored with phosphatic stalagmite, and phosphatic stalactites hang from the roof. The beds often contain the carcases of sea birds, as well as of seals and sea lions which have wandered on to the islands and been engulfed in the soft guano.

Birds inhabit these islands during the breeding season in myriads. They are sometimes almost as thick as there is standing room. On one small island in February, 1911, Dr. Forbes estimated there were 10,000,000 birds. Thanks to these crowds the guano may accumulate at the rate of 1½ inches

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in a year; but, despite its renewal, the supply is now inadequate even for local consumption.

The Peruvian Government engaged Dr. H. O. Forbes to persuade the birds to provide more. While he was engaged in his mission in February, 1911, the birds suddenly flew from the islands, and their abandoned young died in millions. Dr. Forbes attributes their flight to alarm at an earthquake. He recommended various steps to increase the supply and save waste, such as the removal of pinnacles which lessen the collecting surface. One effect of the report was the murder of the President of Peru in the revolution that followed its publication; and in 1915 the Peruvian Congress passed a law prohibiting any further export of guano, and cancelling the concession to the Peruvian Corporation.

The birds resort to the islands for safety. On the mainland they would fall an easy prey to carnivorous animals, and their eggs would be taken by snakes and lizards unless they settled on ledges on cliffs where the wind would destroy the nests and prevent any accumulation of guano. That the birds are conscious of the danger of laying their eggs on a mainland was impressed on me in Spitsbergen by a Norwegian walrus hunter, according to whom the birds on the off-lying islands do not lay their eggs until they are protected from the foxes by the breaking of the last ice connection with the mainland. He described the birds as sitting in rows along the cliffs watching until the last isthmus of ice is severed, when they at once waddle to their selected nesting place and lay their eggs!

Guano therefore collects in large quantities only on small islets, and these are restricted to a few coasts by meteorological factors. The most valuable materials in guano are the nitrogenous compounds, such as the ammonium salts; they are easily soluble and quickly washed out by rain. Professor Johnston justly observed that "A single day of English rain would dissolve out and carry into the sea a considerable portion of one of the largest accumulations; a single year of English weather would cause many of them entirely to disappear" (Johnston, 1841, p. 315).

Hence guano can only accumulate in an arid region; and arid islets are very exceptional; but owing to the cold

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current which flows northward along the western coasts of South America, South Africa, and Western Australia, the islands off them are almost rainless. It is only under such meteorological conditions that nitrogenous guano can be formed in quantities of commercial value. The name is, however, used in a somewhat wider sense to include any deposits of excrement. Small supplies occur in caves in various parts of the world. Some of them, as in Barbuda, are due to birds, while "bat guano" is formed of bat dung. "Fish guano" is made of whale flesh, and is a by-product of the whale fishery; and, according to Addyman (1893, p. 130), "the name guano is so popular with farmers that many compound artificial manures are sold as guano."

(c) Leached Guano.

True guano is therefore limited to small islands which are sufficiently spread along a great length of land to be the breeding home of vast flocks of birds, and where the climate is sufficiently rainless to allow the soluble salts to accumulate. In a less arid climate the soluble nitrogenous salts in bird excrement are washed away by the rain, and the less soluble phosphatic residue is known as leached guano or phosphatic guano.

The rapid change in the composition of guano due to percolating rain water is shown by the following analyses of samples collected by Dr. H. O. Forbes:—

	Gannet Guano. (Sula variegata and S. nebouxii.)		Shag Guano. (Phalacocorax bougainvillei.)	
	Fresh.	One Year Old.	Fresh.	One Year Old,
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Nitrogen, - -	12·60	2·80	14·70	9·66
Potash, - -	1·25	2·25	1·70	1·80
Phosphoric Acid,	9·82	13·17	6·00	6·70

During this process some of the phosphate may be dissolved and redeposited in thin enamel-like layers known as crust

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guano, of which the following is an analysis, sent by Dr. Forbes of a sample collected by him in Peru:—

Crust $1\frac{1}{8}$ inches thick on rocks exposed to the full sun.

Nitrogen, - - -	0·28	per cent.
Potash, - - - -	2·58	,,
Phosphoric Acid, - -	37·75	,,

(*d*) Rock Phosphate.

Guano is a short-lived product, and its main contribution to the world's supply of fertilisers is as the parent of many rock phosphates. The phosphoric acid dissolved from guano in a moist climate percolates into the underlying rocks. If they are limestone the phosphoric acid replaces the carbonic acid, and the rock is thus converted into phosphate of lime. Fortunately in the regions where sea birds are most abundant many of the islands are raised coral reefs; and part of them are phosphatised into phosphatic limestone, as in Christmas and Ocean Islands. Where the bird accumulations have taken place on volcanic islands the phosphoric acid replaces the silica in the igneous rocks, which are converted into aluminium phosphate. Thus the phosphate of Clipperton Atoll was found by Sir Jethro Teall to be an altered trachyte. It has retained its original structure, which is recognisable under the microscope; but the rock consists of 95 per cent. of hydrous phosphates of aluminium and iron (Teall, 1898, pp. 230-232). It is a phosphatic pseudomorph of an acid lava.

The warmer regions of the world supply the necessary association of raised coral reefs and innumerable sea birds; so they are the main source of high-grade phosphatic limestone (*cf.* Fig. 1). None of it is worked farther from the Equator than the latitude of 50°, and the bulk of the supply comes from the tropics and sub-tropics. The raised coral islands of the Western Pacific and the Indian Ocean supplied, in 1912, 159,000 tons of high-grade phosphate from Christmas Island, 300,000 tons from Ocean Island, in the Gilbert Archipelago, and Nauru Island, in the Marshall Archipelago, 60,000 tons from the Pelew Islands, and 40,000 tons from Makatea, off Tahiti.

Christmas Island.—Christmas Island is an excellent illustration of these coral phosphates. It is a small island, which is sufficiently near Java to have been the resort of great numbers

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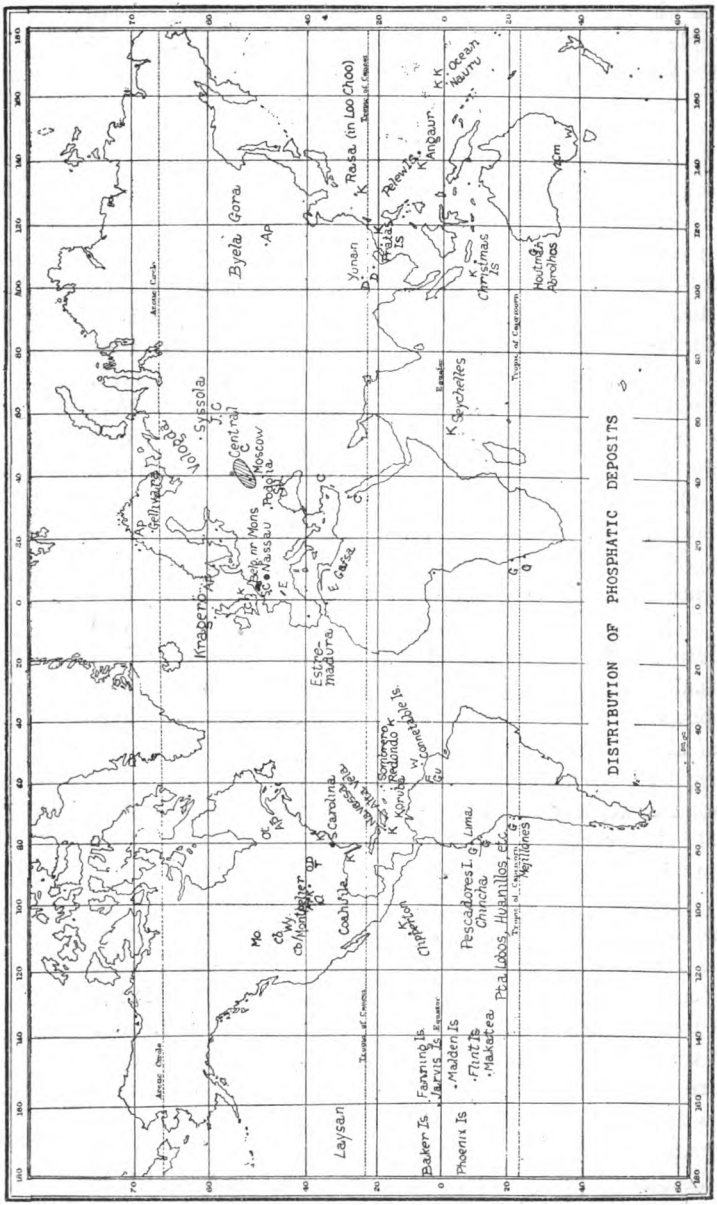

Fig. 1.

G = Guano.		D = Devonian.	
K = Kainozoic.		Sil = Silurian.	
(E = Eocene.)		O = Ordovician.	
C = Cretaceous.		Cm = Cambrian.	
J = Jurassic.		Ap = Precambrian Apatites, &c.	
Cb = Carboniferous.		W = Wavellite.	

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of birds, and yet sufficiently isolated to be free from carnivorous animals. The discovery of the phosphates there is due to the acumen of our great oceanographer, the late Sir John Murray. Dr. J. J. Lister landed on the island during the voyage of the "Egeria" in 1887, and collected some rock samples, which were submitted to Sir John Murray. They were analysed by J. C. Irvine, who proved them to be rich phosphate. Mainly owing to Murray's efforts the island was annexed, and the phosphatic deposits worked by a British company. The island was investigated by Dr. C. W. Andrews (1900), of the British Museum, who showed that it has a volcanic foundation covered by a limestone hood, which includes beds ranging in date from Miocene to Pleistocene. At one time it must have been a low coral reef, and it was then the home of innumerable sea birds. The phosphoric acid from their excrement was carried by rain water into the underlying limestone, which was converted into rock phosphate.

This material was once the subject of an important Australian law case, which led to a legal decision as to the definition of guano and rock phosphate. The importers claimed the Christmas Island phosphate as guano, and therefore as free from harbour duty. The harbour authorities claimed that it is rock phosphate, and therefore not entitled to this exemption. After a costly trial the Court decided that the material is rock phosphate. This determination was all the more just, as the material includes both amorphous phosphate and innumerable veins of crystalline phosphate, which I identified, in 1902, as staffelite, as it is a negative fibrous fluophosphate.

Dr. A. Scott has kindly analysed the mineral of one of these veins from a sample used in the Melbourne trial, and his results are as follows:—

Christmas Island.		Staffelite from Encourtiech. *After Lacroix* (1910, p. 559).
CaO,	53·19	52·32
P_2O_5,	39·56	40·00
F,	1·81	3·36
CO_2,	2·20	5·30
H_2O,	2·51	
	99·27	100·98

with traces of Al_2O_3, Fe_2O_3, and SiO_2.

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The fluorine is somewhat lower than my recollection of a sample in which the fluorine was determined in 1902.

I am indebted to the Pacific Phosphate Company for the following determinations of calcium fluoride in a series of samples of the phosphate of Ocean Island:—2·26%, 2·70%, 2·71%, 3·10%, 3·25%, 3·35%.

The Christmas Island vein phosphate consists of crystalline prismatic fibres or rods, which are optically negative, and are more distinctively developed than in quercyite. It may therefore be identified as a staffelite low in fluorine (Plate VI., Figs. 1 and 2).

Still larger supplies of rock phosphate come from the Western Pacific, and especially from Ocean Island, where one of the characteristic rocks is a rich phosphatic oolite (Plate VII., Fig. 1), with the oolitic grains often surrounded by crystalline phosphate. Nauru, or Pleasant Island, which has been described in detail by Dr. Elschner, and has rich phosphates, is about 160 miles to the west of Ocean Island. It is a member of the Marshall Archipelago, and Nauru Island was included among the German South Sea Islands; but it is worked by a British company, the Pacific Phosphate Company.

At one time much phosphate was worked in the West Indies. It there occurred in small islands situated, like Sombrero, off the larger islands, or like Oruba, off the South American coast. Sombrero (*e.g.*, Julien, 1867) is a small barren island near Anguilla. The phosphate includes 43 per cent. of tricalcic phosphate and 30 per cent. of aluminium phosphate, and is traversed by veins of a crystalline phosphorite. The phosphate was no doubt due to the alteration of the rocks by phosphoric acid derived from overlying deposits of guano. Some of the West Indian phosphates are formed upon the volcanic islands; thus at Redonda the mineral is a phosphatised andesite; its working, after a long interval, was renewed by a British company in 1907. On the volcanic islands the descent of the phosphoric acid has given rise to ferruginous aluminium phosphates. They are more costly to convert into soluble phosphate, and their product tends to become damp. Hence they are very inferior in value to the lime phosphate. Their treatment has never been largely undertaken in this country; they

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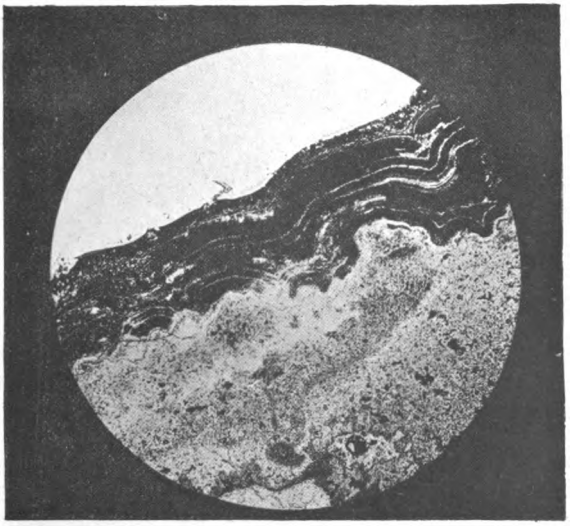
FIG. 1.



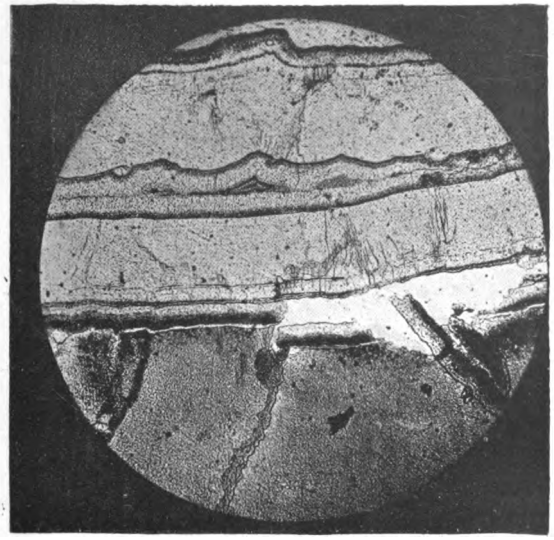


FIG. 2. *Photos. S. Fingland.*

Fig. 1.—Banded staffelite on collophanite in the Phosphatic Limestone of Christmas Island. Seen in thin section, ordinary light: × 24.

Fig 2.—A fibrous staffelite vein in the Phosphatic Limestone of Christmas Island. Ordinary light: × 24.

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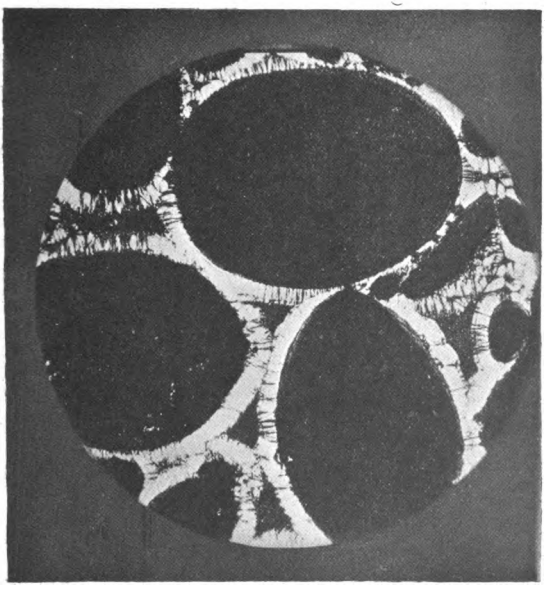
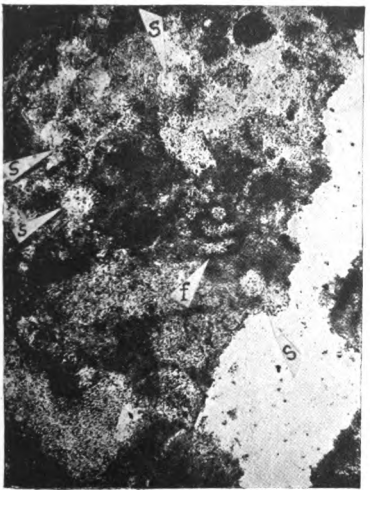
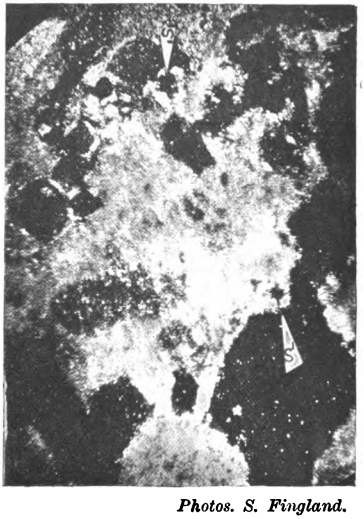
FIG. 1.







Photos. S. Fingland.

(*a*) FIG. 2. (*b*)

Fig. 1.—Aureoles of crystalline fibrous phosphate (probably staffelite) around oölitic granules of amorphous phosphate. In the Phosphatic Limestone of Ocean Island. Under crossed nicols: × 24.

Fig. 2.—The phosphatic globules—the spherulites of de Mercy—in the Phosphatic Chalk of Beauval: × 66.

(*a*) Under ordinary light. (*b*) Under crossed nicols. S—the spherulites; S^1—the spherulites showing black cross; f—foraminifera.

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have been used in the United States, partly for the manufacture of alum and the purification of sewage. They have rarely paid to work for fertiliser. These volcanic phosphates would, however, be available for use if the lime phosphates were ever completely exhausted.

(*e*) The North American Phosphates.

The tropical phosphates are of great interest owing to the clear evidence as to their origin. The chief supplies of phosphate at the present time come from the warmer temperate regions which yield at present, roughly, 6,000,000 tons of phosphate per annum in comparison with 600,000 tons from the tropical coral islands. The origin of these vast deposits has given rise to prolonged controversy, and is by no means fully settled. The most important commercially are those in the south-western States of America.

Florida.—The Florida phosphates are at present the most important in America. They were discovered, according to Millar (1891), by the Government Surveyor, Le Barron, in the winter of 1884-5, though their discovery in 1883 has been also reported. Their working began in 1888 on a small scale, but it rapidly developed, and led to a phosphate boom. The phosphate region extends through the northern half of the peninsula for a length of over 150 miles, about 20 miles from the western coast. The phosphate deposits are of two chief types. The rock phosphate consists of boulders, sometimes a ton in weight, in a matrix of clay and soft phosphate. The material, wherever it is now being mined, lies on the Vicksburg limestones (Lower Oligocene). A photograph by Matson (1915, Plate XIII.A) of a mine at Newberry shows the rock phosphate occupying hollows in the Peninsula limestone (the middle member of the Vicksburg series), pinnacles of which rise into the phosphate. In some places the phosphate is very disturbed, and masses of it have slid down large slickensided surfaces. Such cases leave no doubt that the phosphate has sunk into hollows formed by the solution of the underlying limestones.

Dr. F. Wyatt (1892, p. 69) has also called attention to the great disturbances in the deposits; and he urged that much of

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the phosphatisation happened along cracks and fissures with a general trend of north-east and south-west.

The second type of Florida phosphate is known as "pebble phosphate." It was the first worked in Florida, and as it was dredged from the rivers it was called river-pebble phosphate. The "land-pebble" phosphate occurs on two horizons. The older consists of beds of phosphatic nodules (see, *e.g.*, Matson, 1915, p. 34, Plate VIII.B), which are interstratified in the clays of the Alum Bluff formation (the uppermost member of the Oligocene system). This material is too deeply buried to be of present commercial value, but its existence is important as proving the existence of contemporary phosphate formations in the Oligocene. The Alum Bluff formation is so widely distributed through the pebble area that it is locally known as "bed rock."

The main Florida supply of pebble phosphate is the Bone Valley gravel, part of which consists of rounded pebbles of phosphate in sand or clay. The thickness of the gravel is sometimes as much as 50 feet, but only one-third of this is phosphate. These deposits contain many vertebrate fossils which appear to have been washed out of older beds, as in no case has a skull been found with the rest of the skeleton. The bones represent land animals, such as the horse, mastodon, and rhinoceros, and estuarine mammals, including the manatee, and they are associated with phosphatised marine shells. Matson considers that the height of the bed indicates its Miocene age, though it may belong to the base of the Pliocene.

The first explanation of the Florida rock phosphate attributed it to the phosphatisation of limestone from guano. Wyatt, in 1892, attributed the phosphoric acid to the remains of animals which inhabited estuaries that once covered the region. Brown, in 1904, held that the phosphoric acid was derived partly from guano, partly from phosphate in the limestone, and to some extent from animals with phosphatic shells. According to Sellards (1910), whose theory appears to be now widely adopted in the United States, the phosphate was concentrated, not from grains in the same limestone, but from a hypothetical, overlying, low-grade phosphatic limestone.

The argument that has been advanced against the formation

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of this phosphate rock from guano deposits does not appear conclusive. On the uplift of the country the higher bosses of Vicksburg limestones probably formed a series of low islands; and the sporadic nature of the deposits is strikingly similar to that of rock phosphates formed in guano islands. Guano naturally accumulates most thickly in hollows, and the solutions drain into them, so that their floors are intensely phosphatised. The stratigraphical evidence against the guano theory does not seem complete.

The late Professor Tarr made the interesting suggestion that the phosphate was due to hurricanes, such as that which devastated the Gulf Coast in 1893. The larger marine vertebrates may have been washed ashore, and there mixed with drowned land animals. As Florida lies in the track of the West Indian hurricanes, they may have periodically deposited accumulations of phosphatic material in bands parallel with the western coast of the peninsula.

South Carolina.—The phosphate of South Carolina was known as early as 1795, and was described by various geologists as marl. Its recognition as phosphate was apparently by Shepard in 1859. The Civil War delayed the use of this discovery, and mining was not begun until 1867. At first both river and rock phosphates were worked. The deposits extended along the coast on both sides of Charleston and up the valley of the Edisto River; and they occur in irregular basins from a few acres to a few square miles in area. The chief phosphate is a bed known as the Edisto marl, which rests unconformably on the Eocene, and was shown by Dall, in 1894, to belong to the lower Miocene. When unaltered it is a yellowish white marl from 4 to 5 feet thick. Where phosphatised it is reduced on an average to about 1 foot in thickness; it has been converted into an irregular honeycombed mass, with the hollows filled with sandy clay, and containing remains of Miocene, Pliocene, and Pleistocene vertebrates which have been washed into them. The phosphate has been described as a nodule bed, as in places it has been so honeycombed that it has broken *in situ* into nodules. It is, however, a continuous bed, and the older theories, which were based upon the belief that it was a seam of nodules collected by water,

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are untenable. G. S. Rogers (1914, p. 205) explains it as a residual soil formed from the underlying Eocene Cooper marl, which contains 3 per cent. of phosphate. According to Rogers, this bed was raised above sea-level in early Miocene times, and its disintegration formed a richly phosphatic soil. The region then sank slightly, and was occupied by estuaries, in which accumulated the remains of fish and aquatic reptiles, and of animals that lived on the islands. On the re-elevation of the land the carbonate of lime was leached out of the marl and replaced by phosphate. The Edisto marl was thus converted into a continuous bed of phosphate, which contains about 60 per cent. of tricalcic phosphate.

Tennessee.—The Tennessee phosphates include the largest reserves in the eastern United States. They at present yield about 400,000 tons per annum. The chief deposit is a brown friable rock known as "brown phosphate," which was discovered in 1893, and is mined in four counties. It occurs in beds up to 8 feet in thickness, which consist of thin alternate seams of phosphate and clay; some of this phosphate contains from 68 to 78 per cent. of tricalcic phosphate. These beds have been formed as a residual concentrate left by solution of the Ordovician limestone; they have sunk into solution hollows, and the limestone projects into them as bosses, called "nigger heads"—possibly from their hardness. The brown phosphate is covered by an overburden varying from a few inches to 30 feet; and the industry has become much more prosperous since this material has been removed by steam shovels, and the underlying phosphate worked by hydraulic sluicing, a method borrowed from alluvial gold mining.

The blue phosphate, which is Devonian in age, is mined only in Hickman and Perry counties. It sometimes consists of nodules in a glauconitic greensand. It may contain from 55 to 60 per cent. of tricalcic phosphate, and occurs in beds which are usually not more than 20 inches thick, though they are sometimes 50 inches thick. The beds are covered by a firm roof of shale, but mining under these conditions is necessarily far more costly than with the brown phosphate.

The white phosphate, a third variety, is of more scientific than commercial significance. It was formed in late geological

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times by the action of phosphoric acid derived from the Ordovician beds on Carboniferous limestone.

The Rocky Mountain Phosphates.—The vastest known reserves of phosphate in the world have been discovered in recent years along the Rocky Mountains in the States of Utah, Idaho, Wyoming, and southern Montana. They range from Ogden, north-westward, parallel to the general trend of the mountains, till they cross the Northern Pacific Railway at Elliston, in Montana.* The phosphate rocks occur in a thick series of shales and limestones, which in the southern districts is known as the Park City Formation. This division belongs to the upper part of the Pennsylvanian, the upper section of the American Carboniferous. Gale and Richards (1910, p. 476) report that *Productus semireticulatus* is the most abundant fossil in the limestone overlying the phosphates. In Wyoming the phosphates occur in the Embar Formation, of which the commonest fossil is *P. nevadensis;* it is associated with *P. cora* and *P. subhorridus*, of which the latter also occurs in the Park City Formation. Blackwelder (1911, pp. 457-459) assigns the Wyoming phosphates to the late Pennsylvanian, while Richards and Mansfield suggest the possibility of their northern extension in Montana being of Permian age. The Montana phosphates are overlain by the Woodside limestone, including the Ammonite *Meekoceras;* and the age of the limestone is given as Lower Trias, Permo-Carboniferous, or Carboniferous (Richards and Mansfield, 1911, p. 392). The evidence of the fossils is, however, in favour of all the phosphate being on approximately the same horizon and being of Upper Carboniferous age.

The chief phosphate rocks are brown to grey phosphatic shale and phosphatic oolitic limestone. The mineral is sometimes so black that at Montpelier it was prospected for coal (Gale and Richards, 1910, pp. 462-463). The phosphatised beds may be as much as 200 feet in thickness, and as much as 75 feet may yield on an average from 30 to 50 per cent. of tricalcic phosphate. As a rule, the phosphoric acid is regularly distributed, and shows little evidence of subsequent concentra-

* The range of this phosphate has been described in the *U.S. Geol. Surv. Bulletins*, No. 315, pp. 449-462; No. 430, pp. 457-551; No. 470, pp. 371-483.

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tion, but on the uptilted edges the beds have been enriched to 83 per cent., as at Montpelier (Gale and Richards, 1910, p. 468). At Montpelier, in Idaho, the chief bed is an oolitic limestone from 5 to 6 feet thick, and containing up to 70 per cent. of tricalcic phosphate. The oolitic grains are sometimes surrounded by banded zones composed of crystalline fibres of phosphate. W. T. Schaller has examined a thin slide of this rock, and regards the isotropic phosphate as collophanite and the double refracting as possibly quercyite (Richards and Mansfield, 1911, pp. 377-378).

The rocks in which the phosphates occur have been much faulted and bent into a series of folds, of which the western limb is sometimes vertical and sometimes overfolded. In places, as at Beavers' Creek, near Ogden (Blackwelder, 1910, p. 548), the phosphate beds lie in a flat synclinal, and can be more economically mined. Near Elliston, in Montana, the southern outcrops are in a fault block, and they are 6 feet thick, and contain 61 per cent. of tricalcic phosphate; in the northern part of this field the phosphate rock is from 3 to 5 feet thick, and averages 65 per cent. of tricalcium phosphate.

The interesting problem connected with the origin of these deposits is what occasioned such widespread concentration of phosphoric acid in these shales and oolites. The original source of the phosphate is undetermined. Richards and Mansfield (1911, p. 376) quote, with obvious distrust, the suggestion by Koenig that it came from the rapid growth of an unknown protozoan. Girty, in evidence published by the same authors, has recognised that one variety containing 33·8 per cent. of phosphoric acid is a phosphatised limestone made up of the shells of bivalve molluscs. Girty also notices the occurrence of *Lingula*, which has a phosphatic shell; but such organisms as *Lingula* cannot have secreted enough to explain these phosphates. The associated limestones sometimes contain several per cent. of phosphoric acid (Weeks and Ferrier, 1907, p. 460).

The phosphatisation was probably due to the concentration of phosphoric acid by the prolonged solution of the carbonate of lime after the elevation of this marine series above sea-level at the close of the Carboniferous; during this process phosphoric acid derived from many organisms converted the cal-

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careous material into phosphate. The phosphate, it is interesting to note in this connection, is often very low in carbon dioxide, the amount varying in one series of analyses from 1·72 per cent. to 6 per cent. The same analyses show that the amount of fluorine is low, ranging in these from ·4 to ·6 per cent.

The quantity of the phosphate is colossal. Richards and Mansfield (1911, pp. 437-439) estimate the amount in the area considered in their report as 1,425,920,000 long tons, and that the fields contain a total of 2,500,000,000 long tons of rock containing 70 per cent. of tricalcic phosphate.

The material has not been worked except to a small extent at Montpelier, for it occurs in a district where the local demand for fertilisers is still insignificant, while it is too remote from the great agricultural districts to pay for transport. It represents, however, a reserve of phosphate which will be of incalculable assistance to the west central States of America when they have reached a higher state of agricultural development, and it would supply the eastern States if the price of phosphate rose owing to the exhaustion of more accessible supplies.

(*f*) Algerian and Tunisian Phosphates.

The greatest reserves of phosphate in the Old World occur in the Eocene rocks of Algeria and Tunis. They extend through Northern Algeria from Boghari, south of Algiers, to the phosphate area of Bordj bou Arréridj; in Tunisia the line bends southward past Tebessa, where the deposits are similar to those of Bordj bou Arréridj, to Gafsa, on the hills to the north of the vast salt lake, the Shott al Jerid.

The phosphates are of two chief kinds—phosphate nodules in marl, and phosphatic chalk. The nodule beds have proved commercially unprofitable, and are not now worked. The phosphatic chalks, on the other hand, have been extensively mined for a quarter of a century, and the known reserve of high-grade material is estimated at 300,000,000 tons. This phosphatic chalk is a friable granular limestone containing grains of phosphate, sand, and fragments of fossils. The phosphatic limestones belong to a series of gypseous marls, limestones, and shales, which are all of Eocene age. The beds

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of phosphate are as much as 10 feet thick, and several occur in the same section. Thus three beds are worked at Tebessa, in the great quarries south of Jebel Dyr, which were opened in 1892 by those pioneers in Tunisian phosphate production, Messrs. Crookston Brothers, of Glasgow. These beds lie on gypseous marls, and are covered by chert-bearing marls. The lowest of these beds is 10 feet thick; it contains from 60 to 70 per cent. of tricalcic phosphate, and lies below a bed of nummulitic limestone, which shows that the Tebessa phosphates are Lower Eocene in age.

In southern Tunisia, on the hills overlooking the great depression of the Shotts, are the great phosphate quarries of Gafsa—now the most productive single phosphate mine in the world. It contains four principal beds of phosphate which belong to the Middle Eocene series; the two lower beds are worked and of these the lower is 10 feet thick and the upper is 6 feet thick. By mixing the material from these two beds the product sold has an average of 60 per cent. of tricalcic phosphate combined with 13 per cent. of carbonate of lime.

The general character of these North African phosphates indicates that they were formed as granular deposits on the sea floor. The percentage of phosphate is so high as to indicate contemporary concentration, which was probably due to offshore currents sweeping away the finer material. The concentration may have been continued by solution of the limestone, though I am not aware of any direct evidence of this action.

(*g*) Egyptian Phosphate.

Further east in Egypt are valuable phosphate deposits, which are older than those of Tunisia, as they occur in the upper Cretaceous. They are situated to the west of the Red Sea between Kosseir and the Nile at Koneh. Some of these deposits were held by a Tunisian corporation, which, however, did not retain its interest in them. The mines in 1913 yielded 101,000 tons of an average grade of 65 per cent. of tricalcic phosphate, and it is claimed as equal in quality to that of Tunis or Florida. The chief producer is the Egyptian Phosphate Company; its mines are 20 miles inland, and the phosphate is carried by railway to Port Safaga, 250 miles south of

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Suez. Twelve miles inland from Kosseir are the mines of an Italian company. The Egyptian phosphate is shipped to Japan, as the high dues of the Suez Canal practically exclude it from the European market.

(*h*) European Phosphates.

Phosphate mining was begun in Europe, where it is now relatively unimportant. The mines of England and Germany are closed. The apatite veins of Spain and Scandinavia yield only a small quantity; the output has fallen greatly in France and Belgium, and it is still small in Russia, the one European supply which may be of great future importance.

France.—The French phosphates are geologically the most interesting in Europe, and they are of two chief kinds. The most important is the phosphatic chalk and its residual concentrations, which occur chiefly in the district of the Somme, in the zone of *Actinocamax quadrata* of the Upper Chalk.

One important centre is Doullens, to the north-west of Albert; the deposits were also worked near Peronne and between the Somme and the Aisne. This phosphate field extends into Belgium. The phosphate occurs in this district in two different conditions; some of it exists as large lenticular sheets and bands of grey chalk, from 20 to 80 feet thick, which are charged with phosphatic grains; it also occurs as concretionary sheets and layers, which line pipes and rest in broad depressions in the chalk (Olry, 1889, and Lasme, 1890). The mineral is fluophosphate, with a composition practically identical with that of fluor-apatite.

Various suggestions have been made as to the origin of these phosphates. Ortlieb (1889) regarded them, and the Mons Phosphate of Belgium, as derived from organic deposits of the nature of guano. Delfortie (1872) attributed the phosphates of South-Western France to a similar source. De Mercey, on the other hand, held that the phosphoric acid entered the chalk as ascending solutions through thermal springs, since the distribution of the deposits coincides with the dominant crust fractures of the region. De Mercey was an engineer engaged in the working of these Somme phosphates, and was intimately acquainted with them and their distribution. He recognised

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that, whatever their origin, the phosphatic materials had been concentrated by surface waters; but he held with Olry (1889) that the phosphatic granules are often crystalline and sub-crystalline concretions which he identified as spherulites, and therefore as evidence of some form of igneous or thermal action (Mercey, 1891, p. 861). He claimed, moreover, that the fluorine and other constituents of the phosphatic chalk are all consistent with mineralisation by deep-seated mineral waters (*ibid.*, p. 865). The mineralogical evidence is inconclusive, and De Mercey's case depends on the distribution of the phosphatised masses. He points out that they occur along fault lines and mainly on three parallel lines along the Authie, the Somme, and the Bresle. Along the anticline of the Authie occur the numerous deposits around Doullens, and those between the Authie and the Canche; and on the continuation of the same line are the phosphates near Peronne, and also, farther to the south-east, the phosphatic chalk of Villers-devant-le-Thour, near Rethel, in the French Department of the Ardennes.

This distribution of the phosphates is, however, consistent with the superficial origin of the phosphate, since the fractures would also have admitted surface waters, which might have collected the phosphatic grains into workable deposits. The arrangement of the valley system of this part of France was clearly determined by fractures formed during the uplift of the country; and though such fissures would have facilitated the ascent of hot waters, the general evidence appears to be against the plutonic origin of the phosphate. The richest deposits, as shown in the sections by Lasne (1890) in the phosphate beds near Doullens, were clearly concentrated by meteoric waters. They are residual concentrates due to the solution of some of the chalk and the subsidence of the insoluble phosphatic grains into pipes and hollows. These phosphatic beds are thus similar in origin to the Bullhead bed in the London basin, which consists of a layer of flints left by the solution of the chalk.

The problem regarding the Somme phosphate is therefore the origin of its phosphatic grains. Some of them are spherical bodies which are composed of radiating fibres, and undercrossed

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nicols show a black cross. Such are shown, for example, on Plate VII. (*s* on Fig. 2*a* and 2*b*). De Mercey identified them as spherulites, and as evidence that the primary source of the phosphorus was deep-seated and inorganic. They are associated with phosphatised foraminifera and other fossils. These phosphatic "spherulites" are no doubt due to some inorganic, but not to an igneous, process. They were probably formed by some phosphoric acid of organic origin having been dissolved, and redeposited as concretions of crystalline phosphate. They are no evidence of the deep-seated source of the phosphoric acid. The associated fluorine occurs in proportions which are consistent with either its superficial or its deep-seated origin. Phosphoric acid is no doubt sometimes of plutonic origin; but it is usually and characteristically organic, and the absence from the Somme phosphates of such materials as boric acid, which are distinctively of an igneous and deep-seated origin, renders it safer to attribute the phosphate to an organic origin.

Carnot and others suggested that the phosphate was largely due to decomposed fish remains; but as the phosphatic granules are only from $\frac{1}{80}$th to $\frac{1}{120}$th of an inch in diameter they appear to have been formed from very minute organisms. According to Lasne, they were mainly foraminifera and calcareous algæ. He holds that they were phosphatised while passing through a layer of water rich in phosphoric acid during their fall to the sea floor; for he considers that the change did not take place there or after the formation of the rock, since the fossils which lived on the sea floor, such as oysters and echinoids, have not been phosphatised. This argument is not conclusive, as the less permeable fossils would have been less easily altered.

The phosphate grains in these chalks contain from 66 to 87 per cent. of tricalcic phosphate, and often over 6 per cent. of calcium fluoride. They have been concentrated into workable deposits by the solution of the grey chalk, which, according to Lasne, has in places been almost entirely removed. The flints above the phosphate beds contain many casts of sea urchins, such as *Echinocorys;* hence large quantities of chalk must have been removed. The solution was probably facili-

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tated and guided by the earth movements that disturbed the district, and thus arose that coincidence between the distribution of the phosphatic pockets and the fracture system of northern France which suggested the deep-seated origin of the phosphate.

The concentration of the phosphate was, however, doubtless in part due to temporary cessation in the deposition of the chalk, during which the removal of the calcareous material left layers of phosphatic sand similar to some of the phosphatic limestones of North Africa.

The second important type of French phosphate is found in the South-Western Departments, including Lozère, Aveyron, Lot, Tarn-et-Garonne, and Tarn. They are said to have been discovered by Poumarède in 1869 owing to the exceptional fertility of the ground along certain lines. The phosphates are partly crystalline, and include quercyite, dahllite, &c.; they occur in veins traversing the Jurassic rocks. Hence they were at first attributed to hot plutonic water bringing up phosphoric acid and producing phosphate along clefts in the Jurassic limestones. Their formation by descending water has, however, been more generally adopted, as by Professor Lacroix, who has made them the subject of a series of careful mineralogical researches (1910, i., 2, 3, pp. 555-591). Some overlying bone beds have been claimed as the source of their phosphoric acid; but that view was dismissed, as these bones retain their phosphate. Dieulafait (1885) considers that in Eocene times this country was covered by a series of lagoons, and that phosphoric acid, derived from the lagoon deposits and from phosphatic grains scattered through the Mesozoic limestones, was carried down and deposited as phosphate of lime along fissures.

The French phosphates include some less important deposits, such as the layers of phosphatic nodules in the Lias of Lorraine (Bleicher, 1892).

Belgium.—The Belgian phosphate occurs mainly in the province of Hainaut around Mons, and represents a continuation of the phosphatic chalk of north-eastern France. It occurs in the Upper Chalk. The material is comparatively low grade, as it only contains 50 per cent. of tricalcic phosphate, but the

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quality is improved by mixture with high-grade Florida phosphate. The output has fallen in recent years, but it is still considerable, amounting in 1913 to 219,420 tons. The local manufacture is stimulated by the intensive agriculture by which Belgium supports its dense population.

Russia.—The Russian phosphate fields are very extensive. The phosphate of Podolia, along the Galician Frontier and in Bessarabia, contains 23 to 28 per cent. of tricalcic phosphate, and occurs in the Silurian rocks; it is partly nodular and partly in veins, the podolite of Chirvinski (a variety of dahllite). In Podolia the beds range over 1500 square miles, and De Hautpick estimates the supplies at 80,000,000 tons; the deposits also occur in an area of 1500 square miles in Bessarabia.

In Central Russia, in Moscow, Smolensk, Kostroma, Vladimir, &c., Cretaceous glauconitic sands contain 13 to 20 per cent. of phosphate, while the 8 per cent. of potash in the glauconite is also a valuable fertilising constituent.

The northern fields, in the provinces of Vologda and Viatka, yield granular sedimentary phosphates which are Jurassic and Cretaceous in age. These phosphates contain about 36 per cent. of tricalcic phosphate.

The total Russian output in 1913 was only 25,000 tons. The eastern fields offer the best chance of commercial success, since the Ural mines furnish abundant supplies of pyrites, and sulphuric acid can be cheaply produced. In western Russia the conditions are less favourable for the commercial manufacture of superphosphate.

6. The Scottish Torridonian Phosphate.

One of the most remarkable of known phosphates was found in shales belonging to the upper part of the Torridon Sandstone near Cailleach Head, at the end of the peninsula between Loch Broom and Little Loch Broom, in one of the western detached parts of the county of Cromarty. The phosphate is not of the slightest commercial value, but it is of special interest, as it includes the oldest of British fossils, and one of the earliest direct organic remains yet discovered. A specimen collected by the Geological Survey contained some black lenticles, which Sir Jethro Teall recognised as phosphatic. He accordingly

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examined them microscopically for traces of organic structure and found in one of them some spherical bodies about ·01 millimetre in diameter, and some brown fibres about ·004 millimetre in diameter, and up to several tenths of a millimetre in length.* Sir Jethro Teall describes the lamination of the shales as traceable into the lenticles, so they were formed after the deposition of the enclosing shales; but the rock has undergone greater compression where not strengthened by the phosphate cement. The formation of the nodule was therefore after the deposition of the sediments but before the shrinkage of the rock.

Owing to the exceptional interest of these early Scottish fossils, I visited the locality last spring in the hope of finding more. For information as to the precise locality I am indebted to Dr. Horne. The peninsula is crossed by an incomplete ridge of Lewisian rocks and by a fault which passes about 5 furlongs from Cailleach Head. A small stream, not marked on the 6-inch map, flows along the southern part of the fault, beside which the beds are shattered. The phosphate occurs on the southern shore of the peninsula, 290 yards north-west of the fault. The position can be recognised by the fact that all the small islet, Iola Creag Mhor Scoraig, becomes visible at the locality. Further east part of it is hidden by the land. The rocks here dip 30° to the south-east, and the section is as follows:—It begins to the north-west with a green shale covered by a phosphatic layer containing flat, brown inclusions like small pebbles of shale. Then a phosphatic quartzite in which phosphatic material is conspicuous on the roughly columnar joint surfaces. Next is another band of shale followed by 12 feet of quartzite; then a layer of shale composed of four beds of green shale, each from 2 to 4 inches in thickness, and interbedded with sandstone, making a thickness of 6 feet. The sandstone bars in this shale gave no reaction for phosphate, but the brown inclusions in the lower of these four green shales gave a very faint reaction. Then following a 15-foot bed of sandstone separated by a shaly layer from a series of thin bedded sandstones, which, at the base of the exposed cliff,

* They are figured in the *Memoir on the North-Western Highlands*, 1907, pl. lii., fig. 1.

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are bent downward owing to a fault. This fault lies along a gully exposing the thin sandstones on the north-west. On the south-eastern side, at the base, are shales and thin bedded sandstone; above is a massive sandstone about 15 feet thick, covered by irregular slipped sandy beds.

To find the best phosphatic material I tested the layers in the field with nitric acid and ammonium molybdate, and searched most carefully the beds which gave the strongest phosphate reaction. Microscopic sections of the phosphatic sandstone have so far failed to reveal any organic structures, but I have only had time to examine one of the small ferruginous phosphatic lenticles which occur in the shale. As they were poorer in phosphorus than some of the quartzites, they are not, however, very hopeful. The rock that gives the strongest phosphate reaction is a phosphatic quartzite which contains detrital grains of apatite that have probably been derived from the adjacent Lewisian gneisses. The phosphatic concretion described by Sir Jethro Teall may have been formed by the decomposition of some of this apatite and the redeposition of its phosphoric acid in phosphate of lime. Some contemporary organic structures have been preserved during this process, although obliterated from the uncemented shale. Sir Jethro Teall's discovery should stimulate the careful observation of the Torridonian shales in other localities on the chance of their yielding further evidence as to the nature of these early organisms.

7. The Classification of Phosphates.

The phosphates are so varied in character that their classification is difficult, and they are described in a very voluminous and scattered literature. The simplest classification is chronological. Phosphates are known in every geological system, and are worked from nearly all. Their widespread stratigraphical distribution is shown by the examples in the following list:—

Kainozoic,	Pleistocene—Pacific Islands, North Algeria.
	Pliocene—Suffolk Coprolites.
	Miocene—Malta.
	Oligocene—Florida.
	Eocene—Algiers, Tunis.

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Mesozoic, -	Cretaceous—Egypt, Central and North Russia, Belgium, and Northern France. Jurassic—Russia, Skye, France (Lias). Trias—Lunéville.
Palaeozoic, -	Carboniferous—Idaho and adjacent States. Devonian—Tennessee (Blue), Virginia. Silurian—Podolia, Russia. Ordovician—Tennessee (Brown), Arkansas. Cambrian—South Australia.
Eozoic, -	Torridonian—Loch Broom, Scotland. Canadian and Scandinavian Apatites, Nelsonite Dykes in Virginia.

The classification adopted by Professor Penrose (1888) in the important monograph in which he summarised our knowledge of phosphatic geology was as follows:—

Mineral Phosphates,	Apatites,	Fluor-Apatites. Chlor-Apatites.
	Phosphorites,	
Rock Phosphates,	Amorphous Nodular Phosphates,	Loose Nodules. Cemented Nodules or Conglomerates.
	Phosphatic Limestone Beds.	
	Guanos,	Soluble Guanos. Leached Guanos.
	Bone Beds.	

This classification has been adopted by various authorities, *e.g.*, Merrill (1904).

A useful basis of classification is provided by the origin of the phosphates, and it is diagrammatically illustrated in the section, Fig. 2, which traces the phosphoric acid from the primary phosphates scattered through igneous rocks, or collected in veins of pegmatite, or still further concentrated in apatite veins. This phosphoric acid is carried by streams to the sea, where it is collected in concretionary nodules (C.P.), as granular phosphates (G.P^1.) concentrated by the removal of the lighter material by off-shore currents. The consolidation of such phosphates forms phosphatic limestones (G.P^2.). Further, the formation of guano on oceanic islands leads to the alteration of their rocks into phosphatic limestones (G^1.) on coral islands, or into aluminous phosphates (G^2.) on volcanic islands.

The following classification, adopted fourteen years ago, rests on this genetic basis:—

1. Igneous segregations formed within, or on the borders of, igneous rocks, such as the apatite pockets in the Canadian pyroxenites and Scandinavian gneisses, and the nelsonites of Virginia.

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II. Primary vein phosphates.

(*a*) Those due to the ascent of halogen vapours through fissures or joints, such as the apatites of Norway, and probably some of the apatite veins of Canada.

(*b*) Those formed by ascending solutions containing phosphoric acid, such as the phosphorites of Estremadura.

III. Deposits of direct organic phosphates.

(*a*) Guanos—accumulations of bird excrement.

1. Nitrogenous guano.

(*a*) True guano — loose powder, *e.g.*, Peru.

(*b*) Rock guano — coherent guano.

2. Leached or phosphatic guano—Mejillones guano, Malden Island, &c.

(*b*) Bat guanos.

(*c*) Bone Beds.

IV. Phosphatised rocks.

(*a*) Igneous rocks, such as the phosphatised trachyte of Clipperton Atoll (Teall, 1898, p. 330); the phosphatised andesites of Redonda (*e.g.*, Merrill, 1904, p. 266).

(*b*) Phosphatised marl, *e.g.*, at Quercy, in S.-W. France.

(*c*) Phosphatised limestones.

1. From overlying guano, *e.g.*, Aruba (Hughes) and Christmas Island, Nauru and Ocean Islands.

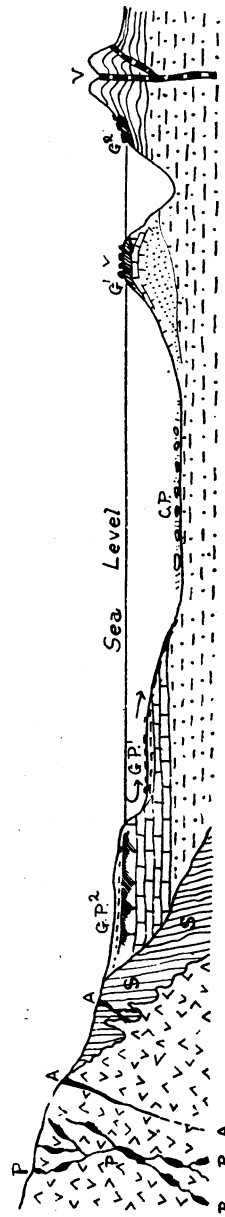

Fig. 2.

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2. From the denudation of overlying granular phosphatic deposits, the Florida rock phosphate (*fide* Sellards and Matson), Tennessee brown phosphate.

V. Granular and nodular phosphatic deposits.

(*a*) Concretionary phosphates concentrated by the slowness of sedimentation on the sea floor, such as the modern, deep-sea, phosphatic nodules.

(*b*) Granular phosphatic limestones. Beds charged with phosphatic grains owing to the phosphatisation of small calcareous organisms. For example, the phosphatic chalks of northern France, Belgium,

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LEGEND TO FIG. 2.

Diagrammatic Section illustrating the Origin and Distribution of Phosphates.

A. Apatite veins in Granite and Slate.
P. Pegmatite veins in Granite.
C.P. Concretions of Phosphate on sea floor.
G.P. ——— Granular Phosphate; $G.P^1$, on sea floor, concentrated on shelf by offshore current represented by arrows; $G.P^2$, upraised on to the land and furnishing the phosphoric acid which has converted the upper part of the underlying limestone to phosphate of lime.
G. Guano; G^1, on the coral island; G^2, on the adjacent shore of Volcano V. The coral limestone below G^1 has been converted to phosphatic limestone; the volcanic rocks below G^2, into an aluminium phosphate.

Volcanic rocks.

Granular sea deposits beneath the coral bank below G^1.

Limestone.

Phosphatised rocks.

Various sedimentary rocks.

Slate.

Granite.

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and the Thames Valley. The phosphatic limestones of Algeria and Tunisia. The Berwyn phosphates—Bala Series, N. Wales.

(*c*) Residual deposits—beds charged with phosphatic granules which have been concentrated by the removal of the more soluble parts of the deposits. The phosphates may remain as scattered nodules, *e.g.*, the Florida pebble phosphates; or as seams which have been broken up during the ablation of the surface, *e.g.*, the Tennessee white phosphates (Hayes, 1901).

VI. Secondary phosphate veins (phosphorite in part) due to the deposition in crystalline form of phosphates derived from organic phosphates.

Some mineral species, such as quercyite, staffelite, dahllite, &c. They may occur in such quantity that, as at Christmas Island, some phosphatised limestone consists largely of vein phosphates.

This classification has the advantage of being genetic, and has the practical convenience of agreeing with commercial practice; for the apatites, though not largely used, form Classes I. and II.; the guanos form Group III., the massive rock phosphates form Group IV., the phosphatic chalks Group V., while Group VI. includes some mineral species only of economic value as accessory constituents, chiefly to Group IV. This classification, moreover, avoids the adoption of the group of phosphorites, which if the term be adopted, should include not only the mineral species found in veins, but some phosphatised rocks.

8. Phosphates and the Principles of Mineral Conservation.

In the working of the mineral resources of a country it should never be forgotten that minerals are irreplaceable. Properly conducted agriculture will yield its products year after year for an indefinite succession of harvests, but, with a few insignificant exceptions, a seam of minerals, once removed, is never renewed. It is true the matter is not destroyed; much iron is used over and over again, but many minerals are so dissipated when used by man that they can only again be

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rendered useful by a process of segregation which is so slow as to be of no immediate value. Minerals, therefore, should be used economically and judicially.

Coal is the basis of British industrial prosperity. Stanley Jevons, in 1865, issued a solemn warning that our coal supplies are not inexhaustible, and that when they are burnt many British industries must cease. He therefore urged that the nation should pay off the National Debt while our coal supply affords adequate wealth. Otherwise he predicted we should leave our descendents burdened with a debt which we should have rendered them incapable of paying by having consumed their fuel as well as our own share. The coal question has been with us ever since Jevons' warning. Successive Coal Commissions, of which the last was in 1901, have pushed the spectre of the British coal famine further and further into the future; for increased supplies of coal have been revealed by discovery of unsuspected extensions of our buried coalfields; the yield of coal from the old fields has been increased by the invention of better methods of working thinner seams; poor, small seams are worked profitably by extracting them with the associated fireclays; mining has been carried deeper, and coal will no doubt be won at depths which were once thought below the practicable limit; and a ton of coal now does more work than formerly owing to its more economical use and to improved furnaces. Nevertheless we have all felt in recent years a steady rise in the price of coal, which there is only too much reason to fear will continue, and possibly at a disastrously accelerated rate. How long our coal supply will last, and at what date the reduction in output owing to the exhaustion of the more easily worked coals will begin to handicap our industries is not part of my problem this evening. Nor do I intend to discuss the question whether, in the interest of national safety, it is advisable to limit the output or export of our coal. But the history of the phosphate industry reminds us of weighty arguments against such restrictions. Experience has often justified the commercial maxim, if you have an asset use it while you can. This principle may be illustrated by reference to the iron ores. British iron mining long ago entered the stage which is threatening our coal. In

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1879 the British iron ores amounted to 93 per cent. of those treated in the United Kingdom. By 1912 the percentage from British ores had fallen to below 68 per cent. Some of the older British iron mines worked ores which could not be used now in competition with richer foreign material, and if they had not been used formerly, they would have remained underground for ever, and their contribution to our national wealth would never have been realised. As they were fortunately used in time they yielded a permanent addition to the national capital, and have thus been a permanent source of income. The judicious conservation of mineral resources avoids alike prodigal waste and the method of the unprofitable and slothful servant who left his talent buried in a napkin underground.

The history of the British phosphate industry illustrates

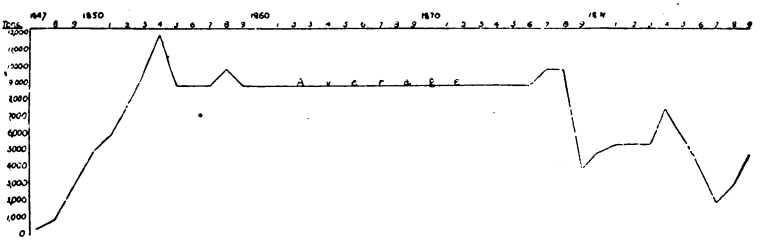

Fig. 3.

The Output of Suffolk Phosphate, 1847-1889.

clearly the danger of restrictions that may be placed upon mineral development in the interests of posterity. The mineral superphosphate industry was begun on the East Anglian coprolites, and, thanks to Lawes' chemical and commercial genius, Britain was for a time the leading centre of superphosphate manufacture. The coprolite beds of East Anglia were worked at a rate which they could not long maintain (Fig. 3). The British output of mineral phosphates reached its maximum in 1876, when the output was 250,000 tons a year. Three years later it fell to 34,000 tons. In 1887 it was only 9894 tons, in 1894 711 tons, and though in 1896 it rose to 3048 tons, since 1900 British phosphate mining has practically ceased. It appears at first sight as if the manufacturers of a generation or two ago had greedily used up the whole commer-

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cially available British supply of raw material, and we may feel tempted to complain that the statesmen of that period allowed a very valuable product to be too rapidly exhausted. But legislative restrictions on phosphate mining would have had deplorable consequences. There are still unused phosphates in Britain; and our phosphate mining collapsed owing to the discovery of extensive supplies of foreign phosphates which are higher in grade and more cheaply mined than our own.

A table (Fig. 4) of the variations in the British and foreign output of phosphates shows that the collapse of British phosphate mining was contemporary with the rise of phosphate

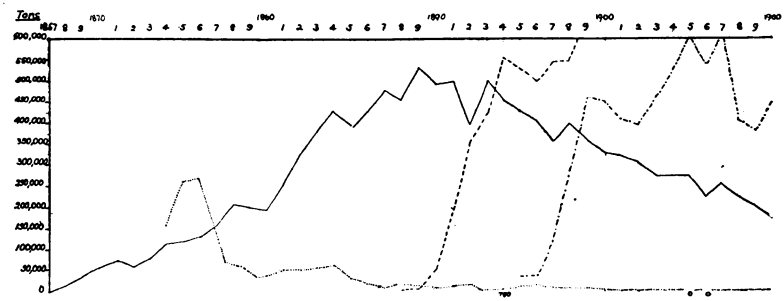

Fig. 4.

THE PRODUCTION OF MINERAL PHOSPHATE.

In Britain, ...
South Carolina, — — —
Florida, — — — —
Tennessee, — · — · —, 1867-1900.

Florida,	1899	=	707,000 tons.
,,	1912	=	2,580,000 ,,
Tennessee,	1912	=	443,000 ,,

working in the south-eastern States of America. With these deposits our mines could not compete. According to O. Fisher (1873) the average yield of the Cambridge phosphates was 300 tons per acre, worth 50s. a ton; the landowner charged £140 per acre as royalty and for the disturbance of his ground. The miner had not only to remove the overburden, but to restore it, and leave the ground suitable for agriculture or pasturage when he had extracted the phosphate. The phosphate bed was seldom more than 10 inches thick, and it did not pay to work when the overburden was 20 feet thick. When prices fell to half the English deposits had no chance in

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competition with the richer phosphates of the waste lands of South Carolina, Florida, and Tennessee. If legislation had restricted the output of British phosphate and prohibited the export of superphosphate so that our supply might last longer, the result would simply have been that large quantities of British phosphate which were profitably mined would have been wasted. If it had not been mined before the discovery of the deposits in the South-Eastern United States that asset would never have been used; and if the British fertiliser industry had been hampered by limiting the output of local raw material or export of superphosphate it would probably never have earned its rich income from the manufacture of foreign phosphates.

It might be suggested that the British phosphates which are still unmined will come to their own later on when the easily worked foreign supplies are exhausted. The near advent of a phosphate famine was once confidently predicted. When Mr. Rooseveldt's impressive rhetoric alarmed the United States as to the rate at which it was exhausting its natural resources, the Federal Geological Survey estimated the available quantity of its important minerals. Mr. F. B. van Horn reported on the supplies of phosphate. He estimated (1909, p. 165) that Florida had only 15,000,000 tons available, or a twelve years' supply, that South Carolina had 3,000,000 tons, which would last not more than fifteen years; and that Tennessee had 103,500,000 tons, which, with the current output, would last one hundred and sixty years, but that it would give out about 1960 owing to the increased drain upon it after the exhaustion of the South Carolina and Florida deposits. The western fields in Utah, Wyoming, and Montana he estimated would furnish a supply for forty-four years. He concluded that with the probable increased rate of production "it will require just twenty-five years to exhaust the available supply of phosphate rock in the United States" (p. 168). He admitted that the period would be lengthened by the large reserves of now unsaleable low-grade rock, and that the western fields might yield more than he expected; but he predicted from the evidence available that the life of the American phosphates must at best be short. He therefore protested against the continued ex-

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port of phosphate from the United States and against America "being drained for the benefit of the worn-out farm lands of foreign countries"; and he proposed that the leases of the new western fields should be granted only for home consumption. "We will have enough to do," he declares (p. 168), "to take care of our own farm lands without shipping our phosphate rock to foreign countries, and in justice to future generations exportation should be stopped."

These alarmist predictions have been discredited by the later estimates of Waggamann, which are abstracted in the American Fertiliser (vol. xli., No. 2, 25th July, 1914, pp. 115-116). According to Waggamann, the quantities of phosphate containing from 58 to 78 per cent. of tricalcic phosphate in the United States are as follows:—

Utah, Idaho, Wyoming, and Montana—High Grade,	2,500,000,000	tons.
Equivalent of all Grades,	7,500,000,000	,,
Florida—High Grade Equivalent of all Grades,	354,300,000	,,
Florida—High Grade Equivalent of Wash Heaps,	20,000,000	,,
Tennessee—High Grade Equivalent of all Grades,	115,075,000	,,
South Carolina—High Grade Equivalent of all Grades,	10,000,000	,,
Arkansas—High Grade Equivalent of all Grades,	26,000,000	,,
Kentucky—High Grade Equivalent of all Grades,	500,000	,,

This supply, he tells us, is sufficient, if properly used, to allow the average production to be trebled, and yet to last for 1100 years.

The still more recent report of the Statistics Committee of the National Fertiliser Association of the United States (American Fertiliser, xlv., No. 3, 5th August, 1916, pp. 21-28) adopts still more favourable estimates, as according to it the supplies of phosphate rock "in sight" in the United States are 5,685,082,600 tons; in North Africa, 316,500,000 tons; in the South Pacific Islands, 62,000,000 tons; and in Christmas Island, 8,000,000 tons.

Even therefore if America refused to let us have phosphate, the supplies from Africa and Oceania would last an indefinite time. There is no reasonable danger of a phosphate famine, and we are no more blameworthy for using as much as we need than were the Phœnicians because they worked out the richest deposits of alluvial tin in Cornwall regardless of the convenience of Chicago and the requirements of the tinned meat trade.

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No. VIII.—A Study of Oil Shales and Torbanites. By H. R. J. Conacher.

[Read 14th December, 1916.]

[Issued separately, 29th June, 1917.]

Introduction.

The oil shales and torbanites form a group of materials which have in common the characteristic that on distillation they yield a product consisting typically of paraffins and olefines, and this feature is the source of their industrial importance.

The Boghead coal or Torbanehill mineral of Armadale and Bathgate, Linlithgowshire, is the type of the torbanites or Boghead coals, and is the material originally distilled in Scotland for the manufacture of mineral oil. For oil-making this coal was exhausted in ten years, and for the past fifty years the Scottish industry has had to rely on the oil shales which occur in the Lothians, Fife, and Lanarkshire.

Two varieties of torbanite occur in Linlithgowshire in the one seam—one brown, the other black. The former is the richer of the two, and of more restricted occurrence. It is very light in weight (sp. gr. about 1·2), tough, almost structureless megascopically, breaks with a conchoidal fracture, thin splinters being translucent and red in colour at the edges, has a light brown streak, and is most resistant to the weather. The black variety differs mainly in being of a dense black colour, with glossy fracture and brownish-black streak.

The Lothians oil shales are heavy, laminated rocks (sp. gr. 1·7 to 2·3), brown to black in colour, with pronounced bedding, which is particularly obvious after weathering or burning. Of the oil shales there are also two varieties—plain shale and "curly." The former is the more usual, and the latter seems to be produced from it by the effect of movements under pressure resulting in contortion of the bedding and the development of numerous slickensides.

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At Armadale the torbanite occurs at the base of the Scottish Coal Measures (immediately above the Millstone Grit), and is associated with typical Coal Measures deposits of sandstone, fireclay, ironstone, and common coal. Closely similar or identical material is known from elsewhere in British Carboniferous rocks, and torbanites of Carboniferous or Permo-Carboniferous age also occur under similar conditions in various parts of Europe; America (Jeffrey, 1910); Africa (Hatch & Rastall, 1913, p. 136); and Australia (James R. M. Robertson, 1892, p. 88; Carne, 1903).

The oil shales of the Lothians occur on a lower horizon than the torbanite, in the upper part of the Calciferous Sandstone series, underlying the Carboniferous Limestone. The associated strata consist of sandstone, fresh-water limestone, so-called marl, fireclay, one or two thin coals, and black shales, only portions of which rank as oil shales.

From the fact that the basis of the Scottish oil industry is a shale, that term is frequently applied to other materials capable of yielding oil by destructive distillation, including such diverse materials as torbanites, bitumens, and limestones, &c., soaked with petroleum, irrespective of whether or not they are laminated clay rocks, which are the essential features of a shale. This use of the term is, of course, quite incorrect.

In September, 1913, the late Mr. W. Fraser, then managing director of the Pumpherston Oil Company, Limited, suggested to the writer that a study of oil shales by means of the microscope would probably yield useful and interesting results, and a beginning was at once made with a series of samples previously collected for megascopic study. The general bearings of the question very quickly emerged, but at the same time it became evident that the comparison of micro-sections with the results of tests of material from the same seam made at different times by various hands was unsatisfactory, not only on account of the varying results got by different workers, but also because of the natural variations in the seam. It therefore became necessary to undertake a series of tests, and these were carried out by a standardised method on samples selected as showing in the highest degree the special qualities of the particular material under test and on quantities as small as possible in order to

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reduce the disparity in size between the sample distilled and that submitted to the microscope. A portion of the sample tested was retained for reference and micro-sections were cut from it. As a guide to the quality of the crude oil produced by distillation, a setting point was determined by observing the temperature at which a drop of oil suspended on the bulb of a thermometer ceased to be fluid, and the specific gravity was determined by means of a 10-gram bottle (or, in the case of very small samples, by suspension of a drop in another liquid, the specific gravity of which was then found by means of the bottle).

The micro-sections made and examined number about two hundred finished sections, while a great many temporary preparations have been made of the spores, &c., of existing cryptogams, and, in view of the algal theory of the origin of the materials under discussion, much attention has been paid to microscopic algæ, and the phenomena of the growth and decay of several species have been kept under regular observation for the past two years.

The samples examined have been personally collected, and their modes of occurrence studied, from various places in the counties of Linlithgow, Midlothian, Lanark, Fife, Stirling, Renfrew, Ayr, Sutherland, Caithness, Inverness, Sussex, Hampshire (Isle of Wight), Dorset, Antrim, while others have been obtained, through the kindness of various friends, from France, Spain, Bulgaria, Siberia, China, Canada, United States, West Indies, Victoria, New South Wales, Tasmania, Iceland. The age of the samples ranges from Ordovician to Recent.

Previous Work.

The lawsuit arising out of the Torbanehill mineral lease (1854) brought forth much evidence, both microscopic and chemical, as to the origin of the "Torbanehill mineral," but little assistance is to be got therefrom, and the same can be said of various vague theories to be found in the publications of the Royal Physical Society of Edinburgh and the Edinburgh Geological Society, and elsewhere during the next thirty or forty years.

Dr. J. R. M. Robertson (1892, p. 110), after discussing the

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various occurrences of torbanite in New South Wales, says, "I see no reason for believing that the origin of this mineral differs essentially from that of other coal seams. It has in all probability been formed by deposition of a particular description of plant life that only flourished in limited areas where the conditions of soil, temperature, and protection existed."

In 1892, Bertrand and Renault published "Pila Bibractensis et le Boghead d'Autun," which was followed by a series of papers dealing with the allied rocks of Scotland, New South Wales, and America. They sought to prove that the Boghead coals or torbanites were composed of accumulations of microscopic gelatinous algæ, preserved by a hypothetical antiseptic solution, which gave to oil shales and torbanites their peculiar characters. They based this theory on the presence in these deposits of enormous numbers of yellow or red bodies showing internal structures remotely resembling the cells of certain recent free-floating microscopic algæ, and assigned the forms found in the torbanites of various countries to definite algal species. This theory was supported by Potonié (1910).

Jeffrey (1910; 1914, p. 735; 1915, p. 220) attacked the algal theory, and urged that the supposed algæ were the deeply sculptured coats of the spores of vascular cryptogams.

David White (1906, p. 26; 1909, p. 50) accepted the algal theory, but according to a later publication (1913, p. 3) he has transferred his support to the spore theory.

Seward (1898, p. 178) expresses doubt as to the organic nature of the structures described by the French investigators, and adds, "It is by no means impossible that further research might lead us to accept the view that the brightly coloured organic-like bodies may be inorganic in origin."

H. M. Cadell (1910, p. 23-24) refers to the "grey shale" of West Calder as being "composed almost entirely of entomostracan remains squeezed together like grains of linseed in a piece of oil cake," and goes on to say, "In this connection it may be noted that entomostraca are exceedingly common in many of the shales, together with fish and plant remains, and it is probable that the large quantity of ammonia in some beds is due to the high percentage of nitrogenous animal matter that they originally contained." But he remarks, "Other

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shales again are almost totally devoid of fossils, although rich in oil and ammonia, and this probably points to the presence of organisms with soft bodies, and no shell or hard covering capable of preservation in the fossil state." At another place (1901, p. 29) he suggests that the numerous fossil fish in a part of the Pumpherston shales have something to do with their unusual richness in nitrogen. In "The Story of the Forth" (1913, p. 8) he suggests that oil shales are derived from an extremely macerated peat embedded in estuarine mud.

D. R. Steuart (1912, p. 164) details some experiments designed to determine the nature of the organic matter of the shales, and comes to the conclusion that it is not of the nature of resin or bitumen, because it is not extracted by solvents of these substances, but that it may be derived from vegetable or animal matter altered by special bacterial action.

W. Scheithauer (1913, p. 12) says, "It would appear that a large number of marine animals perished on certain occasions, probably as the result of volcanic outbreaks, the Scottish shale deposits having been shown to belong to the volcanic region."

John B. Robertson (1914) examined a number of shales and torbanites chemically, and his conclusions are, "There is but little resinous matter in oil shales, the main bulk of the organic material being insoluble in organic solvents," and "the organic matter in oil shales is a decomposition product of vegetable matter (originally algæ, spores, or simply concretions of macerated organic material) similar in nature to that found in peat and in cannel coal, and produced by a definite combination of external conditions." He also says, "There would seem to be no experimental ground for concluding that animal remains are mingled with this vegetable product." The paper contains a most useful series of complete analyses.

E. H. Cunningham-Craig (1916) argues that the oil shales are simply the last stage in the drying up of pretroleum-charged strata, and that certain portions, because of their more absorbent nature and greater affinity for oil, have retained a larger proportion than others, and have become oil shales, while the structures regarded by other authors as alternatively algæ or spores are simply globules of oil solidified on an inorganic or other nucleus.

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Thus there are three distinct theories respectively ascribing the source of the hydrocarbons to—

(1) Animal matter;
(2) Vegetable remains;
(3) Natural petroleum;

with a fourth which makes a blend of Nos. 1 and 2.

Megascopic examination of the Lothian shales gives little guidance as to their origin. In some, shells of ostracods are abundant, while carbonised plant remains—stems, twigs, leaves, roots, cones, &c.—are common enough, but make up a quite inappreciable proportion of the shale.

The microscope reveals a great variety of material—

(1) Very minute carbonised fragments of plants, frequently showing traces of cellular structure, with occasional small spores.
(2) The yellow bodies regarded as algæ, spores, or oil globules.
(3) Shells of minute crustaceans, and bones, teeth, and scales of fish.
(4) Mineral matter consisting of sand grains, crystals of pyrites, &c.

A first survey of this varied collection of débris produces an impression that it is hopeless to attempt to make anything definite out of it. The yellow bodies are of a rather indefinite, rounded, brain-like form, and their identification with the algæ of Bertrand and Renault as seen in the Boghead coals of Scotland, France, and Australia depends rather on colour and outline than on internal structure, as this is rarely well seen in the Lothian shales. The spores generally present in the Lothian shales are not at all of the type found in, say, the Kiltongue, Lillie's, the cannels, the spore bands of the coalfields, or in tasmanite; they are much smaller and more transparent, but bear the tri-radiate ridge typical of the tetraspore (Bennie and Kidston, 1886). They have not been noticed elsewhere, and are so comparatively scarce in the shales that their exact determination seems unimportant.

At the outset a series of sections was prepared from well-known seams (Fraser, Fells, Broxburn, Dunnet, Pumpherston)

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from various localities, the samples sectioned being taken in some cases from definite positions from top to bottom of the seam and from a number of scattered parts of the workings. The examination of these sections showed that the mixture of ingredients is a fairly constant feature of all the shales, but the constituents occur in varying proportions, not only from seam to seam but in different parts of the same seam. The variations, however, seemed to be on so comparatively small a scale as to make it difficult to assign to each constituent its part in giving to the shale its peculiar properties, and it therefore became necessary to seek for allied materials containing the various ingredients in more definite proportions. In previous megascopic study of the subject a collection of such materials had already been accumulated which much simplified matters, and others have been added. In the course of identifying the frequently very fragmentary organic remains and in seeking for the links in the chain of evidence, many blind alleys have had to be followed, but it is not proposed to re-traverse these in the course of the present discussion.

Theory of Animal Origin.

1. *Levenseat Shale.*—This is a strong bluish-black shale containing the usual megascopically visible plant and fish remains, with a few ostracods, and a portion which is crowded with the shells of lingula. The microscope shows that the two materials differ only in the presence of a great mass of shells in the lingula portion (Plate VIII., Figs. 1 and 2), and it might therefore be expected that if animal matter has any bearing on the production of oil shales this part should be richer, and might give an oil of different quality. On distillation the following results are got:—

	Crude Oil. Gals. per Ton.	Sp. Gr.	S.P.
Normal Shale, - - - -	44·7	·895	30° C.
Lingula Portion, - - - -	31·7	·892	31° C.

The lingula portion is thus the poorer in yield, while there is no difference in the quality of the product. It must therefore be assumed that the very large numbers of animals, of whose presence the shells are the visible evidence, have contributed nothing to the oil yield, and their shells have simply constituted

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a dilution of the matter forming the normal shale. This comparison becomes still more striking if the yields of the two materials are referred to an ash-free basis, *i.e.*, the effect of the mineral matter on the yield per ton of shale is eliminated and the comparison restricted to the organic matter. It is then found that the yields are identical. (See Table II., at end.) It may be noted in passing that one-half of the ash of the lingula portion is soluble in hydrochloric acid. This, representing probably the calcium carbonate of the shells, is some measure of the part which animal matter might have been expected to play in the formation of this shale. (See Tables II. and III.)

2. *Thorntonhall Shales.*—These shales occur in the neighbourhood of the Hurlet Limestone at Thorntonhall. The upper one is a tough, blue-black shale, of a somewhat canneloid nature, showing in micro-section both animal and vegetable remains, while the lower shale is crowded with ostracod shells, and contains also fish remains, but no noticeable vegetable matter (Pl. IX., Figs. 1 and 2). On distillation the yields are—

	Crude Oil. Gals. per Ton.	Sp. Gr.	S.P.
Black Shale, - - - - -	29	·910	30° C.
Grey Shale, - - - - -	Trace only.	—	—

3. *Edmondia Shale.*—This shale, occurring below the Arden Limestone, is crowded with the shells of crustaceans, gastropods, lamellibranchs, and possibly cephalopods. Many layers of the shale are completely covered with overlapping shells, most of which are pyritised. The microscope shows a quantity of the usual kinds of vegetable matter lying between the shells. The result of distillation is—

	Gals. per Ton.	Sp. Gr.	S.P.
Crude Oil, - - - - -	9	·949	Below 18° C.

As the vegetable matter present is bound to have yielded oil, and its quantity would have led one to expect more oil than is actually got, it seems necessary to credit the low yield to the vegetable matter, and to attribute its small quantity, evil smell, and poor quality to the action of the sulphur present as pyrites.

4. *Craigen Glen Shale.*—This shale occurs about midway between the Hurlet Limestone and the Hosie, and exactly fits

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Mr. Cadell's description as being crowded with ostracod shells crushed together like grains of linseed in an oil cake. On distillation the yield is—

	Gals. per Ton.	Sp. Gr.	S.P.
Crude Oil, - - - -	43	·880	33° C.

At first sight this seems to be an exception as to origin, but the sections show an abundant supply of the typical vegetable matter lying between the shells. The sample tested came from beside a fault, and was intensely slickensided; in view of other similar occurrences, it seems that this may have improved the quality of the oil.

5. *Kimmeridge "Blackstone."*—This is another apparent exception. Many of the bedding planes are covered with the shells of ammonites of considerable size and of other molluscs, while the mass of the rock shows very numerous seed-like bodies, in shape and size closely resembling ostracods, and it has therefore been supposed that the peculiar properties of this material are due to animal matter. The microscope shows that the supposed ostracods are minute lenses of calcite or siderite—purely mineral segregations—while the other genuine evidences of animal life are so relatively scarce and so irregularly distributed as to be quite inadequate to account for the yield of 58 gallons per ton which the material gives.

The mass of the rock is made up of vegetable matter very similar to that found in some of the other materials, plentifully dusted over with minute crystals of iron pyrites. Probably the presence of the last-named is the cause of the comparatively low yield and the poor quality of the oil (sp. gr., ·996; s.p., below 16° C.).

Unfortunately the optical evidence as to the presence of animal matter is limited to those animals possessing hard parts capable of preservation, and it may be argued that such evidence is not conclusive as soft-bodied animals may have contributed to the shales without leaving any visible trace, but it would certainly be strange if those instances in which animal remains are so prominent to the eye should be just those in which their perishable parts had not influenced the essential characters of the oil shale.

The cholesterol and phytosterol test is of no value when

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applied to shale *oils*, and no one seems to have applied it yet to the shale itself. There remains apparently only the method of investigation just described, and it has been applied to all the material available which seemed to give support to the idea that animal remains are an important contribution to the formation of an oil shale.

In view of the results obtained, and the fact that the richest oil-yielding materials known (the torbanites) give only the rarest sign of the former existence of animal life, it must be assumed, until fresh evidence is available, that animal matter has contributed in no material way to the formation of oil shales and torbanites.

Theories of Vegetable Origin.

It now remains to determine the nature of the vegetable matter present, and whether it is capable of conferring on the shale its distinctive character. For this purpose it is necessary to give attention to coals of various kinds and to some of the allied shales of the coalfields.

For convenience in the foregoing the yellow bodies—the supposed algæ—have been included as vegetable matter, but their exact nature will now be discussed.

That these yellow bodies have some close connection with the yield of oil from the various typical shales is shown by the fact that they occur in similar form in more or less abundance in all the materials so far examined (with the exception of those from New Brunswick, Utah, and Colorado), which yield an oil comparable with that from the Lothian shales. Various other ingredients may or may not be present, but these yellow bodies are a constant feature. (See Tables 2 and 3.)

In the case of the brown Boghead coal, the microscope shows that practically nothing but the yellow bodies is present; there is in addition only a small proportion of opaque amorphous matter* filling the interstices, an occasional streak of bright coal,

* The application of the terms "opaque amorphous matter" and "opaque groundmass" to this constituent is a survival of the early stages of this inquiry, when it defied all attempts to render it transparent, but in thinner sections lately produced it is often revealed as a red structureless material in which is frequently embedded minute débris of spores, &c.

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or a sand grain. The same holds good of the black Boghead, but the percentage of opaque matter is greater, and a series can be made up, with an increasing proportion of opaque groundmass and a diminishing proportion of the yellow bodies, through such materials as the Lillie's Shale, Wheatrigg Gas Coal, Brora Cannel, Cadder Cannel, &c. Comparison of the yields shows that there is a simple connection between the proportion in which these constituents are present and the quantity and nature of the yield; the greater the percentage of the yellow bodies the higher the yield of oil and the larger the proportion of opaque matter the higher the gravity of the oil. It seems that this opaque matter is of the nature of the amorphous groundmass of ordinary coal, and that from it is derived by distillation such products as are characteristic of coal tars (even low-temperature tars), while the yellow bodies are the source of the typical shale products. Although low-temperature distillation brings the products of ordinary coal nearer to the character of the shale product, yet the difference between the two products, even when obtained under identical conditions, is very marked.

From a study of sections of coals and a consideration of recent investigations into the subject, it seems that this opaque matter represents the liquid putrefaction products of vegetable matter, the whole of the cellular structure having been obliterated in the process of decay in water.

This opaque matter in its typical form is absent from the Lothian shales, being apparently represented there by the minute carbonised vegetable fragments (while the brown tinge of the sections may be due to its presence in a dilute form), but it is present to an important degree in the shales of the coalfields (such as the Kiltongue Musselband shale) and in the cannel coals (like the Wheatrigg, Brora, Darnley Parrot). Evidently it is this material that yields the tarry products of distillation, some paraffins, and possibly the bulk of the nitrogenous compounds (including ammonia and the nitrogen combined with hydrocarbons).

As already mentioned, there is division of opinion as to the nature of the all-important yellow bodies. Bertrand and Renault regard them as algæ, Jeffrey considers them to be spores, Cunningham-Craig classes them simply as globules of

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oil—the last relics of dried-up petroleum. It is not proposed to spend time on the full criticism of these theories, but they will be briefly dealt with.

(1) Cunningham-Craig's theory (the most recent) is a resuscitation in a complete and developed form of the vague views put forward at intervals from the time of the Torbanehill trial as to a "bituminous enrichment" of certain beds. It may simply be mentioned that it is difficult to understand how, as in the case of the best torbanites, 10 or 20 per cent. of mineral matter could absorb and hold 80 to 90 per cent. of "inspissated petroleum," and the study of sections of what are unquestionably rocks soaked with inspissated petroleum from various parts of America and Russia fails to reveal anything whatever comparable with the bodies typical of the torbanites, but simply streaks of oil spread through the rock.

In connecting oil shales and torbanites with petroleum, Cunningham-Craig discovers a relationship between the occurrence and richness of the shales and torbanites and the existence of anticlinal structures in the strata. This idea seems to have been first suggested by D. R. Steuart (1912, p. 144) so far as the Lothian shales are concerned, and he gives figures bearing on the point. That the quality of both oil shales and torbanites is capricious is well known, and it is to be expected that a rich part should occasionally coincide with the summit or upper parts of an anticline, but it has yet to be demonstrated that the variation in quality in the direction of the dip is greater than in the direction of the strike.

(2) *Spore Theory.*—In the case of the Wolgan (New South Wales) torbanite considerable support can be found for the spore theory in the existence of a central cavity in almost every individual yellow body, and the resemblance is better appreciated after making a comparison with undoubted spores from other sources. Certain differences exist, however. Spores are very familiar objects in coals (Lomax, 1911, 1913; Bennie and Kidston, 1886, p. 82) and certain shales (*e.g.*, Lillie's), while tasmanite is simply a sandstone containing a very large proportion of these bodies (Twelvetrees, 1912, p. 4; Newton, 1875, p. 339). Originally approximately spherical, as found in coals, tasmanite, &c., they have been so deformed by pressure that the walls are crushed together, and the contents of the cell

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have disappeared (Pl. IX., Fig. 3), while its site may be partly invaded by the embedding material which has found entry through the micropyle or the ruptured spore wall. The originally spherical space is thus reduced to a mere line, which may sometimes ramify, through the folding of the spore coat, but which does not penetrate to the outer boundary (except at the micropyle). In the case of the bodies in the Australian torbanites, the central line generally ramifies considerably, and very frequently traverses the whole length of the body (Pl. VIII., Fig. 4), while in the case of those occurring in the French and Scotch torbanites and in the Scotch and some other shales and cannels, it is totally absent, and its place is frequently taken by a reticulated system of lines wholly inconsistent with the spore idea (Pl. VIII., Fig. 3).

(3) *Algal Theory.*—Bertrand and Renault ask us to suppose that algæ, consisting of water to the extent of about 90 per cent., and of most fragile structure, have been preserved by the action of a hypothetical antiseptic solution, produced possibly from their own decay, and have been enabled to resist pressures which have reduced to discs the robust spherical spores lying beside them, and have flattened branches and trunks of trees to thin sheets of carbonised material, and to escape processes of decay that have converted woody material to a structureless mass. The nature of existing free-floating microscopic algæ—and it is by them that we must judge their ancestors—is such that a slight change of temperature or some other unfavourable circumstance will cause the death and almost instant complete dissolution of the organisms. So rapid is this process that a tubeful of water strongly coloured by the presence of immense numbers of these algæ becomes visibly clearer under the influence of sunlight and the accompanying rise of temperature.

The theory attributes the preservation of the algæ to the action of the antiseptic solution, now represented by the opaque enveloping material, and it might therefore be supposed that the greater the proportion of that groundmass the more perfect would be the preservation of the characteristic structures, but this is by no means the case. In such materials as the Kiltongue shale, the Brora and the Wheatrigg cannels, in which the groundmass is the preponderating constituent, it is rarely

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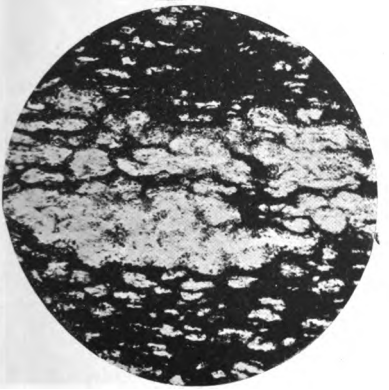
(1.)

(2.)

(3.)

(4.)



Photos. by S. Fingland.

Photomicrographs of Oil Shales.

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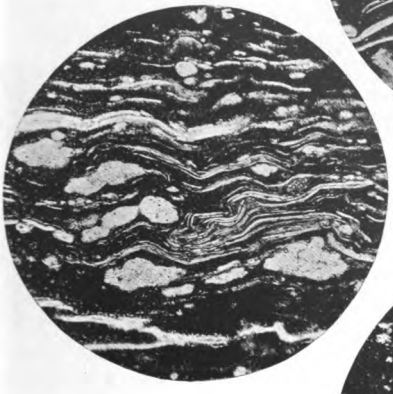
(1.)



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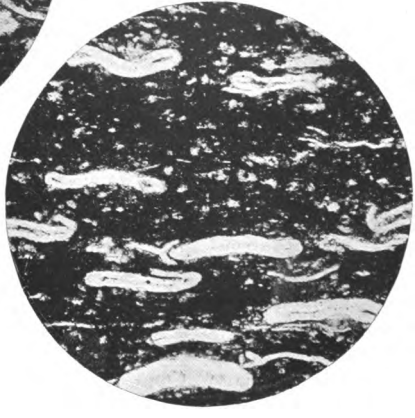

(3.)

Photos. by S. Fingland.

Photomicrographs of Oil Shales.

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that the "algal" structure can be traced in the yellow bodies. On the other hand, it might be urged that it is in the richest materials that the best structures will be found, but in the Hartley Vale torbanite (the richest material known) they are much less perfect than in the Wolgan torbanite (both from New South Wales).

Further, the yellow bodies are to be found with other materials (such as spore cases, ostracod, and other shells) bent around them in a way that shows conclusively that they can never have been the fragile bodies which the algal theory requires (Pl. IX., Fig. 2).

(4) "*Resin*" *Theory.*—From a study of the mode of occurrence of these bodies in a variety of materials the conclusion has been reached that they are simply grains and fragments of resin, and the supposed cell structures are merely the effects of physical and mechanical processes incident to geologic action.

The work of David White and Reinhardt Thiessen (1913, 1914) has shown the prevalence of resin in the vegetation of the Carboniferous period as well as of later times, and that the decay and elimination of the more perishable and woody parts results in a concentration of the resins in the residue. Resins occur in plants as secretions from wounds, and also in definite canals and cells in stem, leaves, and fruits, and vary in consistency from brittle solids to viscous liquids. When occurring in canals they are set free as minute needle-like rods on the decay of the tissue, when in cells they are set free as more or less spherical or subangular grains, and when derived from wounds they are in irregular lumps.

Early in the examination of the shales material was noticed which, from its colour, form, and cracked appearance, and occasional occurrence within the cells of carbonised wood, was tentatively regarded as resin, and a careful study of such occurrences has resulted in the construction of a series of stages in the development of the typical "algal" structures. It seems that in such cases as the French and Scotch torbanites we have simply an accumulation of resin grains (possibly derived from rods or wound lumps by attrition) originally containing a proportion of volatile matter in their constitution, and the evaporation of this, with consequent internal shrinkage and strain, caused the development of a series of cracks, radial and

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reticulated, similar to what is produced in ironstone nodules under a similar process. Sometimes, also, the yellow bodies occurring in these materials present what appears to be a minute cone-in-cone structure, arranged radially with the apices towards the centre and with a small pit where the base of each series of cones rests on the outer boundary of the body, and probably this structure owes its origin to the same inorganic causes, as the more familiar occurrences in ironstones, &c. It is easy to see that sections of such structures at varying angles to their axes would give rise to such appearances as have been regarded as evidence of cellular structure. In studying fossilised tree stems which had been flattened and reduced to a tithe of their original diameter by pressure, it was found that in some cases a complete line of division had been opened from bark to bark through the pith and extending longitudinally through the stem, while in others, more firmly built, a line of incipient fracture had been developed in the same directions. It appears that this is a result of the pressure causing spreading of the timber at right angles to the direction of the force, with consequent rupture along the line of greatest strain. It is conceivable that pressure has acted in the same way on more or less plastic resin fragments to produce the central line ramifying through the yellow bodies of the Australian torbanites and of some of the Scotch shales. The same yielding under pressure seems to have caused the flow of the resin around resisting particles within or adjacent to them (crystals of pyrites are known to occur in recent resins), and has resulted in the formation of the alveolar and cellular structures described by the French authorities in the fossil "algæ." Minute gas bubbles are frequent in resin, being the cause of the cloudiness of some specimens of amber, and it seems probable that the distortion of such gas bubbles and vacuoles has given rise to some of the "algal" structures.

It will be noticed that this view as to the origin of torbanites and oil shales is in conflict with the conclusions reached by D. R. Steuart and John B. Robertson as a result of their chemical work on the question. Their opinion that resins are absent is based solely on the absence of material extractable by the ordinary solvents of resin, but against this it may be

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pointed out that the effect of these solvents is variable. K. Dieterich (1901) says that the results of examination of resins are often very contradictory for various reasons connected with methods of working, &c., and proceeds—"This is especially true of such resins as dammar, copal, and sandarach, which exhibit oftentimes remarkable differences of solubility, even in the hands of unimpeachable authorities, according to the age and origin of the sample and the length of time it has been exposed to air and light after exuding from the parent tree." Further—"The age of the resin and time it has lain on the ground or covered up in the soil exercise great influence on its solubility. When quite fresh both dammar and sandarach are more readily soluble than after a long sojourn in the place of discovery. Thoroughly fossilised resins . . . are in consequence of their age either soluble with great difficulty or almost entirely insoluble."

The resin from the American coals was examined by the U.S. Bureau of Plant Industry, who found that only traces were extracted by chloroform, that alcohol took several weeks to remove one-third of the material in the extractor, and that only small quantities were removed by toluene and ether (White, 1914, p. 81).

It therefore does not seem that the failure to obtain an appreciable amount of extract in the experiments of D. R. Steuart and John B. Robertson is final proof of the absence of resinous material.

The following analyses are interesting as showing the close agreement between the C/H rations of torbanites, oil shales, and resins, and the divergence in the case of other coals:—

	C.	H.	O.	Ratio C/H.	Authority.
Resinous vessel-casts, Montana Coal, - -	76·4	9·3	14·3	8·2	White (1914, p. 68).
Fossil Resin, - - -	78·6	9·5	11·8	6·6	
Torbanite, - - -	84·6	11·0	4·4	7·7	
,, (Black Boghead),	65·72	8·27	6·7	7·95	J. B. Robertson (1914, p. 196).
,, (Wolgan), - -	63·58	7·81	4·41	8·14	
Dunnet, Camps, and Broxburn Shales (average of 9 samples), - - -	16·69	2·3	4·17	7·27	
Coniferous Resin (average), - - - - -	80	11	—	7·2	Thiessen (1913, p. 293).
Coal (Welsh) from - -	90·01	6·71	1·67	13·41	Pollard (1915, pp. 14-31).
,, ,, to - -	95·68	3·04	·51	14·56	

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In the distillation of resin the products obtained do not resemble shale oil, but E. J. Mills (1892, p. 15) remarks that in the process "an approximation is continually in progress towards the composition of the paraffin series," so that it does not appear unreasonable to suggest that the processes which so profoundly alter the nature of woody material in the lapse of geological time (*e.g.*, in the production of anthracite) may bring the resins to a state to yield paraffins on distillation.*

Resin in general contains no nitrogen, and therefore torbanite derived from it should be low in that element. This is indeed the case, as is well known industrially, and is well brought out by the nitrogen contents of the various materials examined by John B. Robertson (1914, p. 196), when recalculated to an ash-free basis—

	Nitrogen Per Cent.	
	On Total Shale.	On Ash-free Shale.
Dunnet Shale,	·49	2·80
,,	·53	2·58
,,	·61	2·48
,,	·67	2·62
,,	·69	2·52
,,	·60	2·40
Camps Shale,	·65	2·11
,,	·53	3·13
Broxburn,	·68	1·78
Torbanite (Black Boghead),	·63	·77
,, Wolgan,	·81	1·05
"Burnt Shale" (Maybrick),	·75	4·75
,, (Curly),	1·23	8·4

Incidentally, the above table brings out another point of interest, viz., that the nitrogen contents (or a portion of them) are left behind on liberation of the oil-forming constituents—a point well recognised in practice, but emphasised in the case of the two "burnt" shales mentioned above—and are therefore probably derived from a different source.

The percentage of nitrogen in ash-free coals is given by Brame (1914, pp. 60-61) as from 1·02 to 1·85; by Carrick Anderson (1897, p. 81), as from 1·65 to 2·11; and by Pollard (1915, pp. 14-31), as from ·19 to 2·22. It will be noticed that the upper limit of these figures is somewhat less than the

* In the discussion of this paper Mr. C. R. Cowie mentioned that on distillation under pressure resins do yield paraffins, a fact which supports the above suggestion.

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average of the figures quoted above for the oil shales, but, if a portion of the organic matter of the shale is resin containing no nitrogen, it might be expected that the nitrogen contents of the shale would be less and not more. The explanation seems to be that certain of the nitrogen compounds are very stable, and resist decomposition, so that they become concentrated along with the resin. Brame (1914, p. 42) remarks, "It is evident that certain of the nitrogen compounds (in coal) are very stable since they do not break down at the high temperature of the gas retort," and ". . . of the nitrogen . . . usually 50 per cent. remains in the coke." In nature the effect of this stability is shown by the increase in the percentage of nitrogen in peat with increase in depth and age, which is remarked on by Brame (1914, p. 23) and by D. R. Steuart (1912, p. 165), and the following figures (Björling & Gissing, 1907, p. 21) illustrate this:—

Depth, - - - - - - -	2·5′	3·6′	4·5′
Percentage of Nitrogen, - - -	1·715	2·509	3·067

It therefore seems that in the production of oil shales and torbanites a double process of concentration goes on which results in the accumulation (1) of the resistant resinous material, and (2) of the stable nitrogen compounds, but while the accumulation of the former material is steadily progressive, a stage is reached with the latter when they break up, and the remaining material then tends towards the composition of a torbanite with reduced nitrogen contents.

With regard to the ash in the brown and black Boghead coals, if these are the result of the elimination of perishable materials, it should follow that there would be a greater percentage of ash in the brown variety, in the case of which the process has proceeded further, but, in fact, the black variety has usually the higher proportion of ash. This apparent anomaly seems to be due to the black torbanite having been formed where it received a larger quantity of detrital mineral matter, a view which is supported by the larger proportion of comparatively coarse material which can be detected in its ash by means of the microscope.

While apparently resin as such is the chief oil-yielding ingredient, it seems likely that resinous matter, such as spores,

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may also be capable of playing the part, but probably to a less extent. D. R. Steuart (1912, p. 164) describes some experiments on this point, distilling lycopodium spore dust mixed with Florida fuller's earth, but apparently overlooks the fact that in the recent material he was dealing with the complete spore, while in the fossil state only the spore coat persists, and this differs in composition from the contents. Accumulations of undoubted spore remains occur in nature, and the results of distillation of two of these can be quoted—tasmanite and a spore coal from Canderrigg, Larkhall. In the former case the product is so polluted with sulphur that no reliance can be placed on the result, while in the latter, although spore coats appear to be the predominant constituent, the product does not seem to have much in common with shale oil, and therefore more evidence is needed to enable an opinion to be formed.

There remain two or three materials tested which are somewhat exceptional—the Kimmeridge "blackstone," the Skye shale, and the brown coals from Victoria and the Isle of Wight, and the "Surturbrand" from Iceland. The first two are of Mesozoic and the three last of Cainozoic age. The products of "blackstone" and Skye shale are characterised by high percentage of sulphur accompanied by a low grade of oil, and in both cases the source of the oil seems to be vegetable. Sections of the "blackstone" show great numbers of lenticular, bright reddish-yellow bodies, flattened along the bedding, showing no hint of internal structure, but plentifully dusted with iron pyrites. Fuller investigation may show these to be resin grains also. In the case of the Skye shale similar reddish material lies in definite bands, also well supplied with pyrites, but it is not quite certain that the granular structure so prominent in the "blackstone" is present here.

The Victorian brown coal approximates to the condition of a peat, containing a very large percentage of water, and the odours released on distillation and the nature of the product also resemble those from peat. It was therefore expected that the distillation of the sample of similar age from the Isle of Wight would yield somewhat similar results, and its relatively high quantity and quality came as a surprise. On account of its very fragile nature no satisfactory section has yet been made

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from it, but megascopic examination reveals the presence of numerous yellow specks which fuse when touched with a hot needle; normally they are brittle, and have every appearance of resin, and it seems likely that this material owes its character to the large proportion of resin present, not only as megascopically visible fragments, but also well distributed through the mass as microscopic particles. In general aspect the material is of a somewhat waxy lustre, devoid of structure, but cubically jointed, and very suggestive of an immature cannel coal. On distillation or burning in the open it gives out a fragrance which is a welcome change from the rank odours of most of the other materials.

The "Surturbrand," although of Cainozoic age, has a very Carboniferous aspect, and on megascopic examination would be classed as very coaly blaes. The small sample appeared to be made up mainly of leaves, and yielded a forked stem several inches long and over 1 inch in diameter in its crushed state. The friability of the material as a whole seems to make successful sections impossible, and only one attempt has yet been made, but the piece of wood has yielded several very interesting sections, which reveal the extremely crushed and collapsed cells of the wood, with medullary rays and resin cells, and lenticels in the bark. A competent botanist to whom the sections were submitted had no hesitation in identifying the wood as coniferous. The inference is that there is a fair amount of resinous matter in the "Surturbrand."

A sample of a black massive material from New Brunswick was distilled; practically the whole mass came over as a heavy tar, leaving a light, shining, porous coke in the retort. Megascopically, the material showed intensely plicated dull and bright bands about $\frac{1}{8}$ inch or less broad, very suggestive of those seen in a streaky, viscous fluid. Micro-section showed distinct flow structure, with a small amount of vegetable and mineral matter arranged in accordance therewith. Quite clearly this is a dried-up petroleum which has picked up sand and plant fragments in its passage through sedimentary strata.

Oil rocks from America and Russia proved to be finely crystalline limestones, entirely devoid of any trace of animal or vegetable matter, with the exception of two or three possible

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ostracods and a doubtful wormcast. In them oil is present in streaks lying along the bedding, but no sign whatever could be detected of the structures typical of the torbanites, and which, if Cunningham-Craig's theory be correct, should be present. On distillation there is considerable difference in the quality of the products, which may have been due to variations in the temperature of the experiments or to differences in the degree of inspissation.

Mode of Formation.

While the probable mode of formation of torbanites and oil shales need not here be discussed at length, some reference to the matter will not be out of place.

The Boghead coal of Linlithgowshire occurs as a lenticular deposit of small area (about 2500 acres), entirely cut off to the east by outcrop, and in other directions thinning out or becoming replaced by common coal, which also sometimes underlies it. It forms part of a normal sequence of coal-bearing strata, and it seems probable that it represents a deposit formed in a swamp fringed with vegetation, but with open water towards the centre sufficiently deep to prohibit the growth of plants. Towards the margins accumulations of plant remains undergoing the normal processes of partial decay were converted into common coal, but such drifted vegetable matter as reached the central area became so completely oxidised as to leave practically only the resistant resin. Where this process had the fullest effect the resulting deposit became converted, in course of time, into brown Boghead coal, while the materials of the black variety were accumulated nearer the fringe of vegetation, where the process of elimination of woody material was less complete. The fringe of growing vegetation, acting as a filter, excluded from the open water towards the centre all but the very finest of the sediment washed into the swamp, and such as did penetrate to the open water would tend to be deposited in the median zone, this accounting for the higher percentage of ash in the black Boghead. Both varieties of Boghead coal contain numerous stigmaria, but these seem to be the evidence of a subsequent phase, when reduction of the water level again permitted plant growth.

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Probably similar conditions gave rise to the torbanites of New South Wales, France, and elsewhere.

In the case of the Lothian oil shales conditions were somewhat different. It is clear that they accumulated as the widespread mudflats of an estuary, and apparently the river which carried the mud brought also a proportion of extremely macerated vegetable matter—possibly, as H. M. Cadell (1913, p. 10) has suggested, the wash from a peat-covered land surface —and the ebb and flow of the tide would aid in the elimination of the woody materials and the concentration of the resin. Occasionally in time of storm a few branches, cones, or leaves were drifted into these back waters to be buried in the mud, and sometimes, as in the Fraser Seam at Tarbrax, trees were able to grow and spread their roots across the ooze.

The conclusions therefore are—

(1) Animal matter has played no appreciable or essential part in giving to either oil shales or torbanites their valuable properties.

(2) The oil-yielding material consists of resin fragments which owe their external form either to their site of origin in the plant or to attrition in transport, modified by subsequent pressure, while the internal structures have been developed (*a*) as shrinkage or pressure cracks; (*b*) by flow around resistant grains; (*c*) by distortion of vacuoles or gas cavities; or by other inorganic processes.

(3) The nitrogen is present wholly or mainly in vegetable débris other than resin.

(4) There is no evidence to support the view that petroleum has played any part in the production of either torbanites or the Lothian shales, or the canneloid shales of the coalfields, but it rather seems that the reverse is the case.

(5) It seems probable from a number of instances that dynamic metamorphism has some influence—other things being equal—on the yield and quality of oil, but this point has not been fully investigated.

It is a pleasure to acknowledge help kindly given in various

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ways in the course of this investigation by Dr. Elizabeth F. Butler, Glasgow; Mr. James Hardie, Sydney, N.S.W.; Mr. P. Macnair, Kelvingrove Museum, Glasgow; and special thanks are due to Mr. George G. Gardiner, of Paisley Technical College, for the facilities given for the carrying out of the numerous tests required.

Note.—Since the foregoing was written a paper on "The Constitution of Coal," by D. T. Jones and R. V. Wheeler (1916), has been brought to the writer's notice. These investigators report that, by extraction of common coal with pyridine and re-extraction of this extract with chloroform, coal can be resolved into cellulosic and resinic portions, the former yielding almost entirely phenols on distillation, while the latter yields paraffins, olefines, and naphthenes. This change in the nature of the products of the resinic constituents they ascribe to polymerisation of the resins under pressure.

It may be pointed out that the result of the present investigation is to show that oil shales and torbanites are derived from the same "mother-substance" as coal by the action of natural processes which segregate the resistant resin portions and alter them dynamically, and that on distillation of the resulting material the paraffins and olefines are mainly or wholly derived from the altered resins, while the relics of the cellulosic substances yield the products more characteristic of coal tar, which conclusions are supported by the chemical work of Jones and Wheeler.

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Table I.

Yields, &c., from various Materials Tested.

Material.	Crude Oil. Gals. per Ton.	Sp. Gr.	S.P. °C.
Brown Boghead,	130	·890	Below 20
Black Boghead,	110	·895	30
Wolgan, N.S.W.,	130	·883	Below 20
Lillie's,	74	·910	29
Kiltongue-Musselband Shale,	35	·890	33
Levenseat (Normal),	44·7	·895	30
Levenseat (Lingula),	31·7	·892	31
Wheatrigg,	51	·944	31
Chapel,	28	·946	31
Brora,	32	·924	27
Craigen Glen,	43	·880	33
Thorntonhall (Black),	29	·910	30
Thorntonhall (Grey),	—	—	—
Edmondia,	9	·949	Below 18
Darnley Parrot,	30	·986	31
Cadder Cannel,	55	·982	33
Skye,	17	1·006	Below 18
Kimmeridge,	58	·996	Below 16
Isle of Wight Brown Coal,	32	·937	40
Iceland,	28	·933	25
Braidwood,	5	·930	Below 20
Victorian,	5	Heavy tarry products.	
Canderrigg Spore Band,	27		
Canderrigg Bright Coal,	31		
Peat,	29	—	—
Oil Rocks (U.S.A., Canada, Russia),	8 10 40 52	From ·898 to ·913	From 21 downwards.

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Table II.

Yields, &c., from various Materials Tested calculated to Ash-free Basis.

Material.	Gals. per ton. Total.	Ash %.	Gals. per ton. Ash-free Basis.	Sp. Gr.	S.P. ° C.
Brown Boghead, - -	130	23·9	171	·890	Below 20
Black Boghead, - -	110	29·6	156	·895	30
Wolgan, - - -	130	25·6	175	·883	Below 20
Lillie's, - - -	74	41·3	126	·910	29
Kiltongue, - - -	35	32·4	52	·890	33
Levenseat (Normal), -	44·7	58·15	107	·895	30
Levenseat (Lingula), -	31·7	71·04	109	·892	31
Wheatrigg, - - -	51	16·50	61	·944	31
Chapel, - - -	28	32·0	41	·946	27
Brora, - - - -	32	31·2	46	·924	27
Craigen Glen, - -	43	59·27	105	·880	33
Thorntonhall (Black), -	29	62·66	78	·910	30
Thorntonhall (Grey), -	—	—	—	—	—
Edmondia, - - -	9	80·62	46	·949	Below 18
Darnley Parrot, - -	30	42·15	52	·986	31
Cadder Cannel, - -	55	14·5	65	·982	33
Skye, - - - -	17	62·0	45	1·006	Below 18
Kimmeridge, - -	58	28·3	81	·996	Below 16
Isle of Wight Brown Coal, - - -	32	7·5	34	·937	40
		Moisture 10 °/₀	39		

Note.—Unfortunately the determination of the percentage of ash was not done on the broken-up material distilled, but was an afterthought carried out on another portion of the same samples, except in the case of the Kiltongue, the ash in which had to be determined from a sample from another locality.

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Table III.

Visible Organic Constituents of Materials Tested.

Material.	Megascopic.			Microscopic.			
	Fish Remains.	Shells.	Plants.	Yellow Bodies.	Ground-mass.	Animal Re-mains.	Wood and Spore Frag-ments.
Brown Boghead,	—	—	x	xxxxx	x	—	—
Black Boghead,	—	—	x	xxxx	xx	—	x
Wolgan,	—	—	—	xxxxx	xx	—	—
Lillie's,	—	—	x	xxxx	xx	—	x
Kiltongue,	x	x	—	xx	xxx	x	xx
Levenseat (Normal),	x	x	x	xxx	x	x	x
Levenseat (Lingula),	x	x	x	xx	x	xxxx	x
Wheatrigg,	—	—	x	xxx	x	—	xxx
Chapel,	x	x	—	x	xx	—	xx
Brora,	—	—	x	x	xx	—	xx
Craigen Glen,	x	x	—	xxx	x	xxxx	x
Thorntonhall (Black),	x	x	x	x	xxx	xx	xxx
Thorntonhall (Grey),	x	x	—	—	x	xxxx	x
Edmondia,	—	x	—	—	xx	xxx	x
Darnley Parrot,	—	—	—	x	xx	—	xx
Cadder Cannel,	—	—	—	x	xx	—	xxx
Skye,	—	x	—	—	x	x	xx
Kimmeridge,	—	x	—	xxx	—	xx	—
Isle of Wight Brown Coal,	—	—	x	—	—	—	—

Note.—No attempt at putting a numerical value on the different constituents is possible megascopically, and this can be done only roughly microscopically. A single x merely indicates the presence of the particular material, but when it forms any considerable proportion of the whole its quantity is indicated by repetition of the sign.

Different methods have been tried for the purpose of assigning a definite proportion or percentage to the various constituents visible in thin section, but no useful result has yet been attained.

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EXPLANATION OF PLATES.

Plate VIII.

Fig. 1.—Levenseat Normal Shale, showing numerous yellow bodies and scarce animal remains in dark groundmass. x 24.

Fig. 2.—Levenseat Lingula Shale, showing very numerous *Lingula* shells in addition to the materials present in the normal shale. The shells show markedly the effects of pressure which the yellow bodies have been able to resist. x 24.

Fig. 3.—Torbanite, Boson, France, showing "Pila" structure in yellow bodies. x 66.

Fig. 4.—Torbanite, Wolgan Valley, New South Wales, showing "Reinschia" structure in yellow bodies. x 66.

Plate IX.

Fig. 1.—Thorntonhall Grey Shale, with very abundant ostracod remains. x 66.

Fig. 2.—Thorntonhall Black Shale, showing well-defined yellow bodies with shells bent around them. x 66.

Fig. 3.—Spores of Tasmanite type in a Canadian shale. x 66.

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No. IX.—The Auld Wives' Lifts. By James Neilson.

[Read 14th December, 1916.]
[Issued separately, 30th December, 1917.]

The Auld Wives' Lifts have—from time immemorial—been looked on as an ancient monument.

This, however, did not (and there was no reason why it should) prevent geologists from inquiring as to the origin of these stones—whether they had come to their present position through natural or human agency. Although certain of our members considered that the stones may have come there through natural causes, yet until the present year of grace only one (Mr. Renwick) had the hardihood to read a paper advocating this view, and his courage seems to have oozed away, as he has never published it.

Our old and esteemed member, the late Dugald Bell, who was our foremost authority on glacial geology, just touches the subject in his charming little book, "Among the Rocks Round Glasgow" (1885, p. 66), thus—

"The 'glacial' or 'iceberg' theory, which some geologists favour, is not without its difficulties, such as the improbability of a glacier or iceberg placing three stones so similar in size in such a position, and the likelihood that, if transported by such an agency, they would be brought from a greater distance and be of different kinds. These and other considerations . . . an observer interested in the subject must weigh for himself."

It seems strange to find Mr. Bell, a man of very strong views, thus halting between two opinions, although it seems to me that his summing up is rather against the glacial origin.

Mr. Renwick has kindly sent me part of his paper, from which I extract the following:—

"From a geological point of view, we are chiefly interested in how these stones have come to be where they are. Considering that the topmost stone weighs about, say, 100 tons, we shall dismiss the idea that the trilith was erected by human agency, as being very improbable, although not absolutely im-

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possible, and only to be seriously entertained if we find that the action of natural forces seems to be inadequate."

After passing lightly over the "glacier" or "iceberg" theory, he says—

"We consider whence they came, and are at once met by the fact that they are of the same rock as is all around on the moor. Upon examining the neighbouring escarpment we find that large blocks are broken off and separated from the main mass of the hill by miniature gullies. Water lodged in the natural fissures of the rock, and, freezing in the winter, has by the consequent expansion forced the blocks apart. Upon becoming exposed on all sides to the weather they get worn down all round, the less solid parts more quickly, and the resulting débris is washed away by the rain. Thus the edge of the plateau has been broken up into masses resembling those known as the Lifts, and we here evidently witness the evolution of a 'cromlech.' . . . Indeed if we suppose it was used in connection with worship, we may more easily account for the absence of small blocks between it and the escarpment of the surrounding amphitheatre."

I think it is rather unfortunate that Mr. Renwick dismissed the idea of human agency, and I consider his theory insufficient to account for the great distance from the nearest escarpment. There are plenty of detached blocks about, but, without exception, these are found on slopes, while the Lifts stand on almost level ground.

Nor does the weathering theory account for the gap, as the rock is a very hard, gritty sandstone, and has been used for millstones (of which there are several yet to be seen only partly cut out), and the faces and edges of the detached blocks look quite fresh, with hardly any sign of weathering.

At a meeting of our Society (May, 1916) Professor Gregory read his paper, entitled "The Auld Wives' Lifts: A Pseudo-Megalithic Tor." He certainly had the courage of his opinions, for he published them in the June Number of the *Scottish Geographical Magazine* (with two figures). I regret that they have not been published in our *Transactions*.

To account for the Lifts, the professor postulates two valleys having a dividing ridge, running north and south, and the

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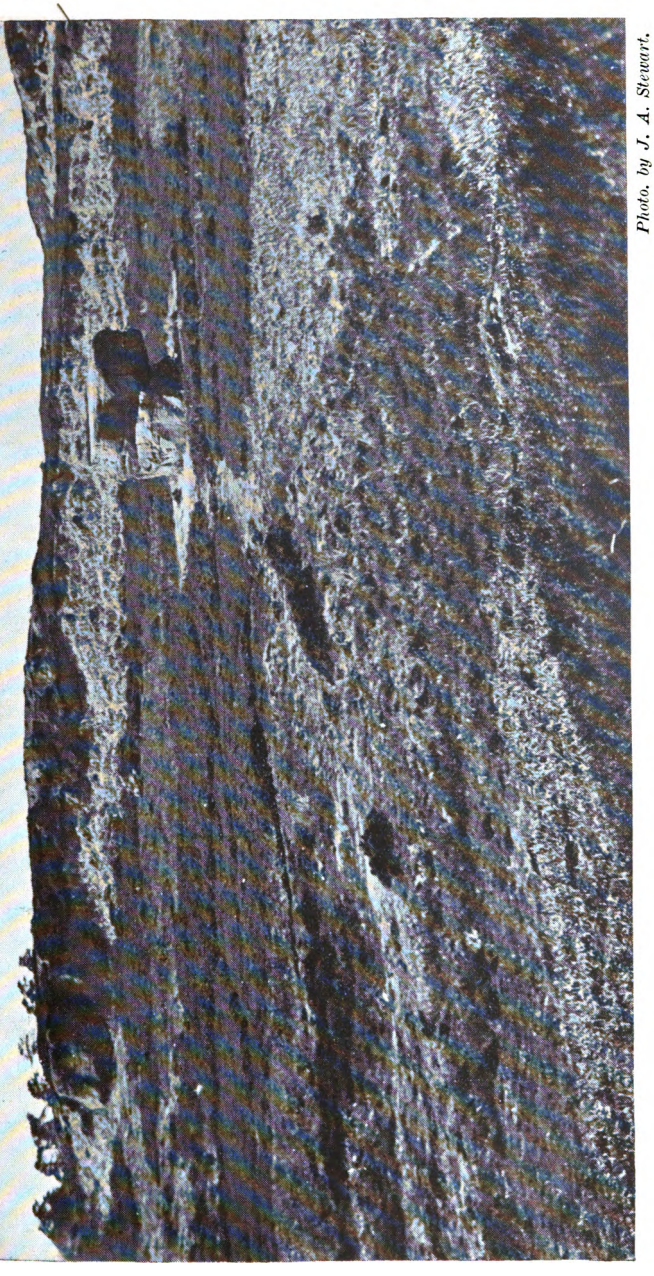

Photo. by J. A. Stewart.

Distant view of Auld Wives' Lifts, from south-east, showing escarpment of amphitheatre.

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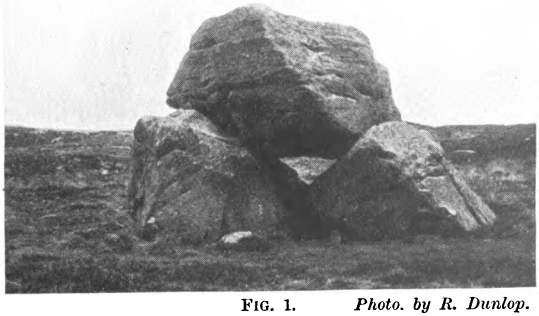

FIG. 1. *Photo. by R. Dunlop.*

Auld Wives' Lifts, from south-west.

(This is the view shown in Prof. Gregory's paper.)

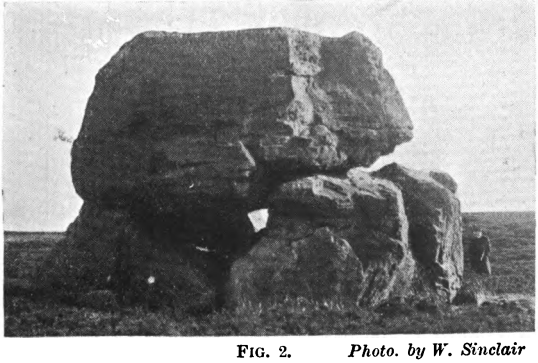

FIG. 2. *Photo. by W. Sinclair*

Auld Wives' Lifts, from north-east.

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boss gradually reduced by wind, rain, and weather to a sandstone tor. (I say postulates, because I can find no evidence of these valleys ever having existed.) He has also expressed the opinion that these two valleys were pre-glacial.

I differ from this theory entirely, for the following reasons:—

(*a*) The valleys could not have been cut by wind, because the prevailing winds of our country are from the south-west, and these valleys would be in a sheltered position, and the stones are in the most sheltered positions in the valleys, so that the great storms would pass over them, and there is no evidence of such wind erosion on any part of the more exposed rocks of the neighbourhood.

(*b*) Wind, rain, and weather have made practically no alteration on the more exposed rocks since the great ice period. (This view will be elaborated further on.)

(*c*) The Lifts rest on a pavement of glaciated rock, which can be traced all round, a fact which is fatal to any valley theory.

(*d*) Thus if the valleys were pre-glacial, the Lifts, standing as a "tor," would have been swept miles away, been ground up and broken, and any fragments left would have been smoothed and scratched similar to other boulders. Besides, the ice could not smooth the underlying rock with the tor in position.

(*e*) If the "tor" was "post-glacial," the valleys would have destroyed all the ice-formed surfaces, and distinct traces of them (*i.e.*, the valleys) would still remain.

Another theory—that of Mr. Stark—is that the Lifts may have been carried—as a single block—in the body of the glacier, and, after attaining their present position, been split and shifted as we see them now, the lower stones sliding apart first, and then the northern one being pushed over the other by ice.

Now, if ice had anything to do with it, some part at least of the stones would have been glaciated, but there are no glacial marks on any of the stones; the surfaces are all rough and the corners all sharp. Besides, if they had been imbedded in the ice long enough for the above movements to have taken place they would have been carried miles (instead of less than 100 yards) from their parent rock.

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My conclusion therefore is that these stones never were exposed to glacial action.

A number of years ago I looked into the question, and the conclusion I then came to was that these stones had not come to their present position through natural causes.

My reasoning was as follows:—These stones must now be either in (*a*) their natural position; or (*b*) must have been shifted to their present position by a force such as ice; or (*c*) must have been erected by man.

(*a*) There is a considerable clear space all round the stones forming a *flat* amphitheatre, entirely clear of the sandstone rock which outcrops all around. I could conceive of no process of natural denudation, either subaerial or submarine, which could clear this space and leave the stones as we see them now. This area being flat, they could not have slid there, so I felt compelled to reject this explanation.

(*b*) *Ice Theory.*—This also bristles with difficulties. An advancing glacier would simply sweep these stones away before it, and a retreating glacier could not leave these without also leaving any amount of moraine matter, which is conspicuous by its absence, and this also applies to the theory that they may have been dropped from floating ice. This, in addition to Mr. Bell's objections, seems fatal.

It seems to me that the present configuration of the rocks in the neighbourhood of the Auld Wives' Lifts is due to glacial action on the peculiar strata of the Craigmaddie sandstones. Their aspect is that of a series of very slightly inclined beds, having precipitous edges, in this respect resembling those volcanic rocks to which the name "trap" has been applied.

The reason of this unusual form I take to be that each of these beds is underlain by a thin bed of mud or shale, so that there is neither adhesion nor cohesion between the overlying and underlying beds. Thus the ice moving from the west-north-west tore off these rocks at the edges and left them in their present precipitous state.

This also accounts for the formation of the north-west side of the amphitheatre, this bed being thinned here and then torn off, and the whole bed swept away south. This bed, from

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which the Lifts have probably been taken, has been entirely swept away (as shown on Plate X.), and the support on which the Lifts rest is the glaciated surface of the underlying bed.

One gets a better idea of the process by going up the hollow, say, a quarter of a mile, above the Lifts, and then turning and walking back in the direction of the ice movement. It is then seen that the hollow both above and below the Lifts is part of the same glacial valley, and that the rocks forming the north-

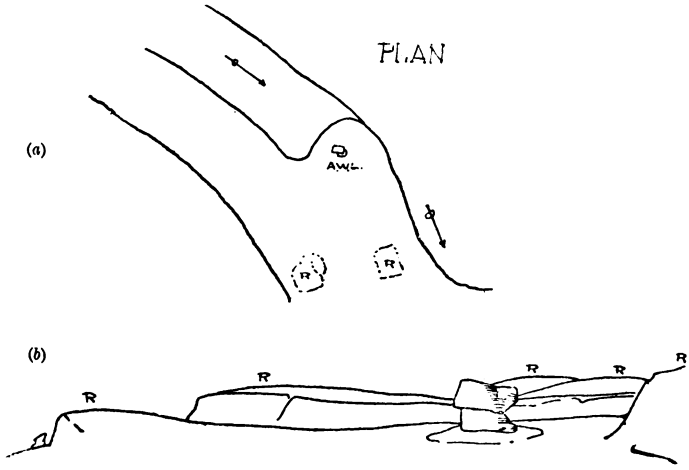

Fig. 1—(*a*) Plan of Amphitheatre.
(*b*) Sketch of same (viewed from south).

The lines show the escarpments formed by the broken-off edges of the various beds.

A.W.L. = Auld Wives Lifts. R. = Roches moutonnées.
—θ— > = Direction of Glacial Striæ.

west side of the amphitheatre have been first thinned and then broken off at right angles to the path of the glacier. The break is different in shape from that of a water or wind shaped valley. The east side of the amphitheatre is formed of a bed of overlying rocks, and the miniature "Whangie" is in this higher bed of rock. The whole width of the valley below the break forms a single symmetrical curve due to the same cause, viz., ice, and formed at the same time.

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It will also be seen that this valley is slightly curved, and that this curve commences above the cross break of the strata. This curve in the ice track is probably due to the steep side of the hill allowing freer escape to the ice.

The evidence of ice action is very distinct. Boulder clay appears to be absent (or if there is any it is covered by peat or moss), and the rocks where exposed are beautifully smoothed and rounded, in the way known as "roche moutonnée." While in numerous parts the glacial striæ can be plainly perceived, in some cases it is as fresh-looking as if it had been only recently done. Practically speaking, these exposed rocks are just as the ice left them, and, taken all over, I question if the effects of wind and water have worn off an average of more than an inch or two since the glacial period. Boulders are rare and small.

It will also be observed that at the lower end of the valley the rock appears nearly across the whole way, and that it is glaciated, which is altogether inconsistent with Professor Gregory's theory, that this hollow is due to either wind or water.

Professor Gregory considers the Auld Wives' Lifts to be a tor, similar, I presume, to those of Dartmoor, which are all or mostly of granite, and the peculiar way in which granite weathers produces these very fantastic results. One thing is necessary, they must be in an exposed position, and their bases kept clear by wind, not overgrown by moss, as are the Auld Wives' Lifts. A very similar structure may be seen among the cyclopean walls about the tops of the Arran mountains.

These have no affinity to the detached blocks on Craigmaddie Moor, which all owe their existence to the undermining of the soft underlying bed *close to a steep slope*, down which the outer stone slips. This accounts for the miniature "Whangie," which belongs to the second bed above that on which the Lifts rest. There are numerous others, *e.g.*, two large ones at the escarpment of the bed on which the Lifts rest, but the finest are on the first high ridge, seen from the road, and near the wood. Here are fantastic forms, which I associate, not with the "Whangie"—which is not beautiful—but with the Fairy Dell, near Loch Ranza. After passing through avenues you

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come to a rock arch which resembles a cromlech in all but that one side and the top are part of the rock *in situ*. This chamber is about 8 feet long and about 6 feet high, the span of the capstone being about 6 feet; it is situated about 30 yards from the wood. There are also to be seen one or two cases of overhanging capstones which were arches till the outside stone slipped away too far.

A *sine qua non* in every case is a steep slope, down which the detached stones could slip, and which is entirely awanting in the case of the Lifts, which stand on a flat area some 40 or 50 yards from the nearest escarpment.

As for the Lifts themselves, they would probably be taken from the nearest escarpment, detached in the manner described, and might possibly originally have been one block. At least I have no objection to that theory.

The two bottom stones seem to have come from the same stratum, and are very much false bedded, so that I read them somewhat differently from Professor Gregory, who says, "The bedding planes in both the supporting stones dip westward about 25°." I think the west stone is in its natural position, while the inner surface of the east stone requires to be lifted up so that it is horizontal, in order to bring it to a corresponding position. They contain bands of conglomerate which can be traced through both stones.

With regard to the theory that the Lifts existed in their present position in one piece, I cannot comprehend how the one lower stone could remain unmoved while the other slid down to a considerable angle, and yet left the top stone horizontal. It seems to me that any movement of this stone would lower the side of the top stone which rests upon it.

It may be noticed that the nose of the right-hand stone is inserted below the other, so that the two stones must have been pushed together before they could assume their present position. In my view the eastern stone was laid down first, and the other pushed hard against it.

(*c*) For these and other reasons I conclude that the Lifts have not come to their present position from natural causes, and the alternative is that they have been placed there by man. That they are, in fact, *a pre-historic monument*, of the

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class known in this country as "cromlechs," and on the Continent as "dolmens," a class which is known over almost half the world.

At first one is staggered by the great size of the stones; how could these be manipulated by people, whom the historians tell us were painted savages. Well, people who could do this work were not savages. Long ago there was a rage for large stones, and each seemed desirous to surpass his predecessor, till at length a time was reached, when the stones became so large that it was impossible to manipulate them, and Egypt and Syria bear evidence of this failure.

The greatest stone lifted by so-called savage people is (so far as I know) that known as Le Menhir Brisé at Lockmariaquer, in Brittany. Its dimensions are given as 67 feet 6 inches in length by 13 feet 6 inches by 7 feet 6 inches, and its weight as 200,000 kilos (about 196 tons).*

It stood on end like an obelisk, but was broken and thrown down by lightning in the eighteenth century.

Mr. Duncan Smith has at my request kindly measured the top stone of the Lifts with the following results:—

Greatest length (between perpendiculars) approximately	21 ft. 6 in.
Greatest breadth, - - - - - - -	13 ft. 0 in.
Average thickness, - - - - - - -	7 ft. 0 in.
Solid contents, - - - - - - -	1134 cubic feet.

Which at 140 lbs. (= 16 ft. per ton) gives about 71 tons.

For comparison I give some sizes of the larger capstones of cromlechs and dolmens (Borlase, p. 433)—

Carrickglass, Co. Sligo,	15 ft. 4 in. × 9 ft. × 8 ft., nearly 70 tons.
Clochmore, Co. Down,	13 ft. 0 in. × 10 ft. × 5 ft., about 50 tons.
Proleck, Co. Down,	15 ft. 0 in. × 13 ft. 6 in. 3 ft. 6 in., about 60 tons.
Kermanstone, Co. Carlow,	22 ft. 10 in. × 10 ft. 9 in. × 4 ft. 6 in., about 100 tons.

* Hutcheson ("Prehistoric Man and Beast," p. 250) states that this stone weighs about 342 tons.

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BRITTANY.

La Mene Ritual, Lockmariaquer,	-	38 ft. × 40 ft.
Mané Lud, Lockmariaquer,	- -	28 ft. × 16 ft.
Table de Merchands, Lockmariaquer,	-	20 ft. × 13 ft.
Crucano, Carnac,	- - - -	24 ft. × 12 ft.

while menhirs or standing stones exist up to 39 feet high above ground.

The stones in the Carnac district are of granite, and are thinner bedded than other rocks would be. This is especially true of the first two in the above list.

Cromlechs may be composed of three or more stones, and the only difference I know of between the Lifts and the typical monument is that the chamber in the Lifts is so small. This I attribute to the men being by this time sick of the job and letting it go, and Borlase gives a number of instances of this kind (p. 432 *et seq.*).

One of his classes is thus defined—"Those in which the performance of a colossal feat of strength in raising and placing in position the most enormous block for a roofing stone obtainable was evidently the first consideration, and the symmetry of the crypt beneath which would of necessity be liable to be upset during the process, a secondary one." He says, "at Kermanstone, Houth, and Woodtown it can scarcely be said that a chamber exists at all," and "In the Kilternan example the crypt is much disarranged, owing apparently to the weight of the roofing stone."

Some cromlechs are surrounded by a rampart, *e.g.*, Giant's Ring, Dumbo, 4 miles from Belfast, the rampart of which is about 600 feet in diameter, but not anything like so grand as the amphitheatre in which the Lifts stand.

Regarding now the Lifts as an ancient monument, let us consider as to its origin and fitness for the worship to which it was an accessory. Our idea is that the natives, observing the beautiful natural amphitheatre and some detached stones lying in the corner, conceived the idea to move the stones into the centre, and build them so as to form a dolmen.

They afterwards proceeded to carve a large ring on the top, and cups and rings (discovered by Mr. Ludovic Mann) on the

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surrounding rocks, and lastly to erect cairns containing tombs in the neighbourhood.

Looked at from any and every point of view it deeply impresses the spectator with a feeling of wonder and awe, that does not grow less as the years go by, and while not questioning the fact that it may be a "pseudo-megalithic tor," we conclude that it is in reality the greatest "ancient monument" of its kind in our country, and one of the grandest in the world.

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No. X.—Hydreionocrinus verrucosus n.sp., Carboniferous, Isle of Man. By Dr. F. A. Bather, F.R.S.

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[Read 8th February, 1917.]

[Issued separately, 30th December, 1917.]

Diagnosis.—A *Hydreionocrinus* with cup depressed and bowl-shaped, flattened on posterior interradius, stem-facet depressed in IBB circlet, having plates equably curved and closely covered with fine pustules. With an interbrachial plate resting in a notch between the radials; in the post. 1R. the corresponding notch is between anal *x* and 1. post. R.

Horizon.—Middle Carboniferous, Poolvash Limestone (Upper *Dibunophyllum* zone, *fide* Wheelton Hind, 1907, p. 148, and 1909, p. 167).

Locality.—Poolvash Bay, Isle of Man.

Holotype.—A complete cup collected by Mr. James L. Begg, and presented by him to the Geological Department of the British Museum, registered E 21591.

Description of the unique Holotype.—Cup depressed and bowl-shaped. IBB not impressed, but slightly excavated for the stem-facet.

Cup-plates equable or very faintly tumid; sutures flush or almost imperceptibly depressed; surface with a uniform shagreen-like ornament of pustules, 3·5 or 4 in 1 mm. linear.

The sub-pentagonal outline and the regular slope of the sides of the cup are disturbed by the anal area, which is more flattened, *i.e.*, approaches the vertical more rapidly.

Antero-posterior diameter, - - -	23·0 mm.
Transverse diameter, - - - -	26·0 mm.
Height from basal plane to fulcral ridge of RR., - - - - - -	9·0 mm.
Diameter of stem-facet, - - - -	6·6 mm.
Depth of excavation of stem-facet, circa	1·2 mm.
Distance of apex of IB. from margin of stem-facet, - - - - circa	2·0 mm.

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IBB. form an almost regular pentagon, with sides normally straight.

BB. therefore pentagonal, except where modified by the anal area. Height, circa 6 mm.; greatest width, 8·2 mm. Post. B. hexagonal, its upper angle being truncated for the support of anal *x*: height, 8 mm.; greatest width, 9 mm.; r. post B. also hexagonal, but not bilaterally symmetrical, its sixth side being a short one which abuts against RA.

RR. approximately pentagonal, *i.e.*, shield-shaped, wide and low, with outer angles truncate, forming a short shoulder. Between these shoulders is a V-shaped notch with concave sides,

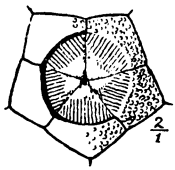

Fig. 1.

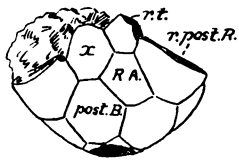

Fig. 2.

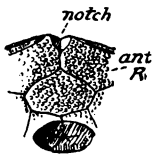

Fig. 3.

HYDREIONOCRINUS VERRUCOSUS.

Fig. 1.—The infrabasal circlet, showing the stem-facet. × 2 diam.

Fig. 2.—The cup from the posterior, showing the anal plates. Nat. size.

Fig. 3.—Part of the cup from the right anterior interradius, showing the notch on the shoulders of the radials.

in which presumably there rested an interbrachial (text-figure 3).

Measurements of Ant. R.—

Greatest width,	12·5 mm.
Width of facet,	10·9 mm.
Width below,	10·7 mm.
Height, to edge of lip,	6·6 mm.

The radial facet slopes upwards to the strongly marked fulcral ridge; its general appearance is much as in *Zeacrinus konincki* Bather (1912, text-figure 11).

The anal plates included in the cup and still preserved are—anal *x*, RA., and *rt.* (text-figure 2). Between anal *x* and l. post. R. is a notch, similar to those between other radials,

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but slightly smaller, and, like them, indicating the presence of a plate. Anal *x* hexagonal, squarely truncate below where it rests on post. B., obliquely truncate above, where it supported a plate of the tube not preserved, but corresponding to that marked *lt* in Bather, 1912, text-figure 2. RA. pentagonal, abutting on r. post. B., post. B., r. post. R., *x*, and *rt*. *rt*. hexagonal, resting on RA., abutting by its sides on *x* and r. post. R. and the succeeding IBr., and supporting on its left shoulder the same tube-plate (*lt*) as was borne by *x*. This arrangement is precisely that of the genotype (see Bather, 1912, text-figure 2).

Stem unknown, but the characters of its proximal joint-face may be inferred from those of the Stem-facet. On the floor of this the IBB. meet round a minute lumen, the precise shape and size of which are indistinguishable. A roughly pentagonal area surrounding this lumen, to a distance of 1·3 mm. from the centre, appears somewhat rough, but devoid of regular ornament. Between this area and the margin of the excavation, each IB. is marked by ridges parallel to its median line, *i.e.*, to the radius. There are about ten of these ridges, with equal intervening grooves, to each IB., which is equivalent to a total width of 3·7 mm. (text-figure 1).

Relations of the Species.—From the genotype, *H. woodianus* De Koninck, this species differs in the equable surface of the cup-plates, those of *H. woodianus* being markedly tumid (Bather, 1912, text-figures 1 and 3).

In this character, as in the general shape, our species is reminiscent of *H.* (?) *phillipsianus* (De Kon. & Le Hon). But the original drawing of that species represents a specimen of almost circular outline, with the anal area slightly protruding rather than flattened (see Bather, 1912, text-figure 6). Anal *x* and *rt* in that species are said to be pentagonal. "Sa surface externe est entièrement lisse et n'offre pas la moindre trace de granulations" (De Koninck & Le Hon, 1854, pp. 88, 89). The measurements given indicate a proportionately higher cup, viz., ·5 of diameter as compared with ·36 in our species.

The specimen from the Hurlet Limestone of Roscobie (James Wright Colln. No. 441; Bather, 1912, pl. viii., fig. 6)

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appears to have had a cup of the same general character as that of *H. woodianus*.

The specimen from Bed 3 at Invertiel (James Wright Colln. No. 727; Bather, 1912, pl. viii., figs. 7, 8) had a distinct granular ornament. Unfortunately the cup in that specimen is not well enough preserved for comparison with that from the Isle of Man.

Our specimen does not seem to agree with any specimen figured by Mr. James Wright (1914).

The presence of an interbrachial plate, if correctly inferred from the notch at the upper angles of the radials, distinguishes this species from those previously described, and even suggests a doubt as to its generic position. But, without further evidence, this need not be taken to outweigh the general characters of the cup and anal area, which agree most closely with *Hydreionocrinus*.

For works referred to, see list at end of the following paper on Ulocrinus (p. 218).

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No. XI.—Some British Specimens of *Ulocrinus*. By Dr. F. A. Bather, F.R.S.

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[Read 8th February, 1917.]

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A Cup from Campsie.

This note was provoked by a specimen which Mr. James L. Begg, of Shettleston, near Glasgow, asked me to name for him. Its description will serve as an introduction to the subject.

Horizon.—Middle Carboniferous, Lower Limestone Series (Upper *Dibunophyllum* zone).

Locality.—Corrie Burn, Campsie, Stirling.

Description of the Specimen.—The specimen is a cup, to which are still attached two columnals (Fig. 1).

The cup is goblet-shaped, with sides approximately vertical in its upper third (radial circlet), expanding slightly in the upper part of the basal circlet, and then tapering with a concave curve to the stem-facet. Height, circa 12 mm. Greatest width, calculated $\left(\frac{10{\cdot}8 + 8{\cdot}2}{2} = \right)$ 9·5 mm. Width at top, calculated $\left(\frac{11 + 7}{2} = \right)$ 9 mm., say $\frac{3}{4}$ of height. Diameter of stem-facet, 2·8 mm.

IBB, 5, of normal pentagonal shape; height, circa 3·7 mm.

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BB, 5, slightly tumid; 4 are hexagonal; height, circa 6·6 mm.; width, 4 mm. below; 5·6 mm. above. r.post.B, heptagonal; its left upper angle being truncated by RA, the length of the abutting side being 1·4 mm.

RR, pentagonal, shield-shaped, with straight sides; width, 5·4 mm.; height, 4·9 mm. r.post.R is not uniform, since, instead of abutting on a basal and a radial, its left sides abut on RA and *rt*. It is rather narrower than the other RR; width, 4·8 mm. The top right-hand angle of l.post.R is truncate.

The Radial Facet occupies the full width of the radial. Its dorsal area is horizontal or slightly sloping from the fulcral

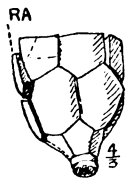

Fig. 1.

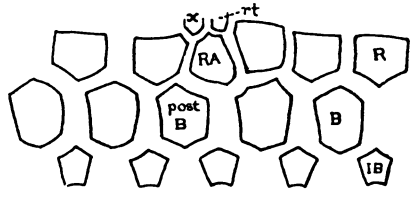

Fig. 2.

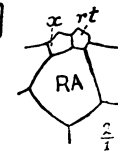

Fig. 3.

ULOCRINUS.

Fig. 1.—View of specimen from Corrie Burn, from right side. × 4/3 diam.

Fig. 2.—Analysis of the cup of the same specimen. × 4/3 diam.

Fig. 3.—Anal area of *U. globularis*, elongate form, from a specimen in Mr. Begg's collection, from Fife. × 2 diam.

ridge outwards and downwards. The dorsal ligament scar is clearly marked, depressed, and apparently wide, as it seems to be bounded by the curved raised margin of the radial and by the fulcral ridge. There is no sign of striation or denticulation. The ridge is broader in the middle than at the angles; its outer limit appears to be straight, except for a slight median notch marking the position of the axial canal, but there are in some radials indications that each half of the ridge passes inwards, in a slight outwardly convex curve, from the angle to the notch. From the ridge broad plates slope strongly inwards and downwards, and bear clear muscle fossæ; but the interarticular ligament fossa is not clearly marked.

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Anals.—The only plate preserved is RA. This has six sides—(1) Abutting on r.post.B; (2) resting on post.B; (3) supporting r.post.R; (4) abutting on l.post.R; (5) supporting an anal, presumably *x*; (6) supporting an anal, presumably *rt*.

The existence of *x* and *rt* is confirmed, and their relations to succeeding tube-plates made known, by other specimens of the same or allied species, as mentioned hereafter. One such is drawn in Fig. 3.

Columnals, two preserved. Proximal slightly widening upwards to a diameter of 2·8 mm., and slightly excavated for reception of IBB, so that its proximal joint-face would have shown five interradial ridges. The stem-facet consequently was not depressed. Second columnal, diameter, 2·5 mm.; height, ·6 mm.; central area depressed, with diameter 1·4 mm.; outer border with about 25 radiating ridges, not very clear; lumen pentagonal, diameter circa ·35 mm., its angles apparently interradial, but the ossicle has been shifted.

Generic Position of this and similar Fossils.

There are known from the Carboniferous Rocks of Great Britain a number of specimens which in the essential composition of the cup agree with that just described. In so far as names have been applied to any of them, they have, as a rule, been referred to *Poteriocrinus*. It is, however, perfectly plain that the anal area differs from that of *Poteriocrinus* in that only one anal plate rests on the posterior basal. This also constitutes a difference from such genera as *Cromyocrinus* and *Eupachycrinus*, to which the specimens are in some respects more closely related, and to which there has been some disposition to refer them. Certain Scottish specimens have been persistently referred to by the Geological Survey as *Pisocrinus globularis*, and this example has been followed till quite recently by other Scottish geologists (*e.g.*, P. Macnair, 1917, p. 188). *Pisocrinus* is a purely Silurian genus, belonging to a different Order, and the only obvious reason for this curious reference is that the genus was established by De Koninck (1858) on the same page as that on which his *Hydreionocrinus* (?) *globularis* was described.

The difficulty of finding a generic resting-place for these

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specimens was due partly to errors in observation, or, at any rate, in description, partly to actual growth-changes in the anal area, but mainly to the simple fact that they presented in that region a new type of structure. It was not till the genus *Ulocrinus* was founded by Miller & Gurley (1890) that there was any labelled compartment in which they could, even provisionally, be placed. Since then I have, with some reservations, referred them to that genus.

The main feature of *Ulocrinus* and of all the British specimens now under consideration is the presence of a single large anal plate, resting not merely on the posterior basal, but also on the shoulder of the right posterior basal. This plate also abuts on the left and right posterior radials; but, though a superficial symmetry has been induced, its relations to them are morphologically distinct. Thus, the side of the right posterior radial on which it abuts is the lower slope, greatly elongated for the purpose; the side of the left posterior radial on which it abuts is the vertical side, here thrown out of the vertical. The relations of this plate to the radial and basal on its right prove it to be the radianal; and the peculiarity of this type of anal area is therefore the upward growth of the radianal and the pushing of the reduced anal *x* almost outside the limits of the dorsal cup or patina. Anal *x* is in fact, morphologically considered, more outside the cup than is the adjacent tube-plate, *rt*, for whereas *rt* abuts against the reduced vertical side of the right posterior radial, anal *x* rests on what is only the shoulder of the left posterior radial. This difference is clearly brought out in Fig. 2, which correctly represents the right posterior radial as at a higher level than the left posterior radial. On the other hand, *x* is still wider than *rt*, as appears more clearly in Fig. 3.

If, however, we consider the species from the Coal Measures of Kansas and Missouri placed in *Ulocrinus* by the authors of that genus, we shall see that in none of them does the anal area precisely correspond with that of the British species (drawings will be found in Bather, 1900, p. 122). The species in which the anal area most nearly resembles that in our specimen is *U. kansasensis* Miller & Gurley (1890). Here the radianal bears the same relations to the adjacent cup-plates,

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but supports only one other anal plate; this may most simply be regarded as *x*, since it is hexagonal, and was presumably followed by *lt*, *x*2, and *rt*. The difference then is simply that *rt* has been squeezed out of the cup. To some extent this may be a result of individual growth, for a specimen from Kinghorn, Fife (B.M., E. 6324 *a*), has both *x* and *rt* outside the cup-limits, while otherwise similar, but smaller, specimens from the same locality and horizon (E 6324, *b* and *c*) have them still within the limits. If, however, *rt* is squeezed out in course of growth, *x* should naturally follow it, and since in *U. kansasensis* this evidently has not happened, the difference cannot be due entirely to individual growth. None the less we might strain a point and place our specimens in the same genus as *Ulocrinus kansasensis*.

But unfortunately the genotype *U. buttsi* Miller & Gurley (1890) does not agree even with *U. kansasensis* in this respect, much less with the British specimens. For in *U. buttsi* the radianal no longer touches the left posterior basal, but the right posterior radial comes between and rests in part on the posterior basal. Thus RA seems to be growing upwards and to have assumed almost the position, though by no means the form, of a typical Cyathocrinid anal *x*. In form it differs through its great width below and its constriction above—indications that the plate is really the radianal with its inferradial relations, and not anal *x* with its supra-radial relations. In *U. buttsi* the radianal is said to support only one small plate (presumably *x*), but the original figure might be interpreted to show the remains of *rt* as well, either resting on *x* and r.post.R, or possibly just passing down to RA.

A British specimen somewhat reminiscent of the *U. buttsi* plan is specimen *h* from zone 33 of St. Monans, submitted to me by Mr. James Wright on 23rd November, 1911, and discussed in my reply of 25th November, quoted by him (1914 *a*, p. 136). I there compared it to *Bursacrinus* or *Delocrinus*, since I provisionally referred the trapezoidal anal to anal *x*. That plate might conceivably be the radianal, but it is wider above than below, extending obliquely to the left, and it abuts on the right posterior radial only on the vertical side; its relations therefore are supra-radial rather than inferradial.

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The anal area of *U. blairi* Miller & Gurley (1893, p. 57) differs from those of the species previously described in that *x* is quite a large plate, and retains a fairly wide connection with the posterior basal. The relations of RA to the adjoining basals and radial are those normal in early Poteriocrinidæ. This species is therefore in a more primitive stage than the other species referred to *Ulocrinus*, and, as I have previously said (1899, p. 32), can with difficulty be retained in the genus. It is probably intermediate between *Ulocrinus* and the more primitive *Cromyocrinus* (not *Eupachycrinus*, as I suggested in 1899).

Cyathocrinus (?) *sangamonensis* Meek & Worthen (1861), of which a figure will be found in the Report of the Geological Survey of Illinois, vol. ii., p. 310, pl. 26, ff. 1*a*, *b*, has recently been referred to *Ulocrinus* by Mr. Kirtley F. Mather (December, 1915, p. 102), but, since the anal plates are arranged precisely as in *U. blairi*, it is not a true representative of the genus.

In the specimens that have been referred to *Ulocrinus* and to similar genera the anal plates appear to have been in a state of relatively rapid movement; movement, that is to say, in both the evolution of the race and the development of the individual. In separating the Inadunate Dicyclic Crinoids into genera, we have been accustomed to attach considerable weight to the relations of the anal plates; but it is doubtful whether it is safe to adopt this basis of classification for the group of forms here discussed. It cannot be doubted that the changes in the anal area are of much physiological importance; they depend on the pressure exerted by the rectum, and this in its turn may be rapidly influenced by variations of food supply. To place all the Dicyclic Inadunate Crinoids that resembled each other in the anal area into a single genus would, as we know, be absurd. The converse proposition may be equally true, namely, that diversity in the anal area need not preclude otherwise similar forms from being placed in a single genus.

A case in point is presented by two species described by Miller & Gurley (1890) as *Eupachycrinus magister* and *E. sphæralis*. These have, it is true, the wide radial facet and depressed base of *Eupachycrinus*, but the radianal is low down in the cup, especially in *E. sphæralis*, and does not support *rt* as in *E.*

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14-*brachiatus*, the genotype of *Eupachycrinus*. The structure is in fact the same as in *Ulocrinus blairi*, and the species bear to *Eupachycrinus* the same relation as *U. blairi* bears to *Cromyocrinus*.

For the various species now in question, the number of individuals accurately described up to the present is not large. The British specimens that have passed through my hands have done so one at a time, at considerable intervals. Such a method of work is wasteful of time and unfruitful in results. Before undertaking any revision of the genera, I should prefer to accumulate and compare the fairly extensive material that is probably dispersed through many collections both public and private.

For the present all the species and specimens herein discussed may be left in *Ulocrinus*.

Specific Relations of British Ulocrini.

The division of the British specimens into species and the provision of correct names is also a task to be postponed, for reasons similar to those affecting the generic division. It may, however, be pointed out that there are two main shapes, a subconical and a globular. These two shapes are respectively exemplified by the specimens to which M'Coy gave the name *Poteriocrinus nuciformis* (April, 1849) and the specimen described by De Koninck (1858) as *Hydreionocrinus* (?) *globularis*.

In the Subconical Shape, of which Mr. Begg's Corrie Burn specimen is an example (Fig. 1), the cup is very slightly constricted above, the height is conspicuously greater than the diameter, and the infrabasals form a high circlet with straight sides or even a concave curve, "giving a pointed appearance to the lower portion of the cup" (M'Coy, 1851, p. 117).

In the Globular Shape the cup is markedly constricted above, the height is but slightly greater or even less than the diameter, and the infrabasals form a low circlet with convex curve, so that the cup in the most marked examples is almost a truncated sphere.

These two shapes include forms capable of further discrimination.

The subconical shape is manifested in Derbyshire (type-

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locality) and Flintshire by a more Conical Form with somewhat massive more or less tumid plates, and with the sides of the infrabasal circlet straight rather than concave.

In Scotland the same shape is represented by smaller, more delicate cups of Goblet Form, with more equable plates, and with more distinctly concave sides to the infrabasal circlet (Fig. 1).

The globular shape as seen in England and Wales is generally of truncate Sphæroidal Form, tending to be wider than high, with smooth almost polished surface and with low infrabasal circlet. This form is found right up to Holy Island.

In Scotland the corresponding shape seems to be a more Elongate Form, tending to be higher than wide, with loftier infrabasal circlet. The appearance of thinner plates with less smooth surface is probably due to conditions of preservation.

All these forms seem, as I have elsewhere said (1912, p. 76), "to characterise a fairly definite horizon"; but how far this may be capable of further zoning, how far the different forms mark differences of time, how far they are merely local races or influenced by diverse conditions of deposit, these questions must be left for further study to determine.

Nomenclature of British Ulocrini.

As to the specific names by which any of these forms may be known a few words are needed.

Poteriocrinus nuciformis M'Coy dates from April, 1849. It is as Wachsmuth & Springer have pointed out (1879, p. 139), not to be confused with *Poteriocrinus nuciformis* (Fischer). This latter combination seems first to have been used by Eichwald in 1859 (p. 588). The species, however, dates from 1837 (possibly a little earlier), when Fischer von Waldheim first described it (p. 151, pl. 41, ff.5, 6) as *Cupressocrinites nuciformis* Goldfuss. Wachsmuth & Springer (1879, p. 139) have considered this as a synonym of *Cromyocrinus simplex* Trautschold (1867). It is no doubt a *Cromyocrinus*, but since it has two arm-rami to the ray it is a synonym of *C. geminatus* Trautschold, which therefore should bear the name *Cromyocrinus nuciformis* Fischer ex Goldf. Unfortunately Wachsmuth &

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Springer (1886, Rev., p. 248, Proc., p. 172) have also referred *P. nuciformis* M'Coy to *Cromyocrinus*, and in this I formerly followed them (H. Woods, 1891, p. 38), so that there would thus be two uses of the name *C. nuciformis*. Since, however, M'Coy's species is not a *Cromyocrinus*, it is not necessary on this ground to give up M'Coy's trivial name.

It is perhaps more to the point to remember that M'Coy himself compared his species with *Poteriocrinus bockschii* Geinitz (1846, p. 549, pl. xxiii., fig. 13). In the figures of that species the radianal is evidently of *Ulocrinus* type, but above it only one plate is shown, presumably anal *x*. Probably *rt* was present, though its precise relation to *x* and r.post.R is uncertain. The type-specimen undoubtedly belongs to our British group, but to the globular rather than to the subconical shape. It most closely resembles the elongate-globular Scottish forms. The measurements of Geinitz' figures are—Height, 11 mm.; greatest width, 10 mm.; width at top, 6 mm. The holotype was found by Herr Markscheider Bocksch near Altwasser or Hausdorf in the Carboniferous beds of Silesia. Where it now is I do not know.

The name *Ulocrinus nuciformis* (M'Coy) may therefore be regarded as valid on nomenclatoral grounds. One cannot, however, leave the species without remarking that unnecessary difficulty has been introduced by the fact that M'Coy's figure 4 is reversed, as also are the adjoining figures 1 and 2 (Bather, 1912, p. 74).

Hydreionocrinus (?) *globularis* De Koninck has elsewhere been discussed by me (1912, p. 74). The slight difference in the position of *rt* is, as already suggested, an individual or growth variation, and the holotype cannot on that ground be separated from the other elongate-globular forms, found like it in Scotland. Whether it should on the other grounds already mentioned be separated from the more sphæroidal English and Welsh forms is a different question. In any case I cannot help thinking that it will prove to be indistinguishable from *P. bockschii*, and that the Scottish forms at any rate will have to be known as *Ulocrinus bockschii* (Geinitz), while the name *U. globularis* will disappear.

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For the present it will be most convenient to speak of—

Ulocrinus nuciformis, conical form. } [Subconical shape].
Ulocrinus nuciformis, goblet form. }
Ulocrinus globularis, spheroidal form. } [Globular shape].
Ulocrinus globularis, elongate form. }

Occurrences of Ulocrinus in Great Britain.

U. nuciformis, Conical Form.

(1) Two syntypes (M'Coy, 1849) in Sedgwick Museum, Cambridge, from Derbyshire. The one figured by M'Coy (1851) is hereby selected as lecto-holotype. Measurements based on M'Coy's description: height, 16·6 mm.; greatest width, 14·9 mm.; width at top, about 10·5 mm.

(2) "*Poteriocrinus nuciformis* M'Coy." Arenaceous or Upper Black Limestone, near Mold, Flintshire. G. H. Morton (1882, p. 54, No. 35). B.M., E 21273. Cup massive, plates tumid; height, 18 mm.; greatest width, 15·5 mm.; width at top, 12·6 mm.

(3) "*Ulocrinus nuciformis*." Redesdale Ironstone low down in zone of *Productus giganteus*, Redesdale, Yorkshire. Hind (1902, p. 464; 1903, p. 216). I was responsible for the determination, but that was fifteen years ago. It may have been a sphæroidal *U. globularis*.

U. nuciformis, Goblet Form.

(1) Two specimens from Craigenglen, Lennoxtown, Stirling; Armstrong Colln., B.M., E 527 *a*, *b*.

	Height.	Greatest width.	Width at top.	Width at stem facet.
(*a*)	8·5	6·75	5·0	1·6 mm.
(*b*)	8·1	7·0	5·3	1·5 mm.

(2) Mr. Begg's specimen from Corrie Burn, here described.

U. globularis, Sphæroidal Form.

(1) Red Limestone with *Woodocrinus*, Quarry above R. Swale at Richmond, Yorkshire. B.M., E 21456.

(2) Holy Island. B.M., E 622.

(3) Near Bowes, Yorkshire, B.M., E 14974. A little crushed below, and BB, perhaps in consequence, slightly tumid.

(4) "*Pentremites acutus*." Upper Black Limestone, near Holywell, Flintshire. G. H. Morton (1882, p. 55, No. 39). B.M., E 21276. Plates rather worn and, perhaps in consequence, slightly tumid. Measurements of above specimens in millimetres:—

	Height.	Greatest width.	Width at top.
(1)	10·5	10·8	mean 6·3
(2)	11·2	11·6	7·6
(3)	circa 9·5	10·0	7·2
(4)	9·0	9·9	6·2
Ratio,	100	105	68

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U. globularis, Elongate Form.

(1) Holotype. Below *Productus giganteus* limestone, near Glasgow. Mus. Pract. Geol., No. 7940.

(2) Hosies Limestone, Bed 19, E. of St. Monans, Fife. Seventeen cups collected by James Wright. B.M., E 15159-15175. These are from the material referred to by J. Wright (Nov., 1914 a, pp. 137-138).

(3) No. 1 [*i.e.*, bottom] bed at Invertiel Quarry, near Kirkcaldy, Fife. Recorded as fairly common by James Wright (1912, p. 54, pl. xviii., fig. 5). A large specimen presented by him is B.M., E 15067. It is somewhat weathered at the top, so that the relative width may be exaggerated. *x* and *rt* are not preserved, only a small part of them having been within the cup limits; RA has a width of 2·6 mm. above, which is relatively great.

(4) No. 2 [*i.e.*, middle] bed at Invertiel. Recorded as very rare by J. Wright (1912, p. 55); is not found higher in this section.

(5) Hurlet Limestone, Seafield Tower, Fife. (Wright, 1914 b, p. 151.)

(6) Hurlet Limestone, Roscobie, Fife. (Wright, 1914 b, p. 153.)

(7) Hurlet Limestone, Kinghorn, Fife. Three cups, B.M., E 6324 *a*, *b*, *c*. Of these, *a* is an old example, with *x* and *rt* outside the cup limits. Width of RA at top, in *a*, 2·4 mm.; in *b*, 1·6 mm.; in *c*, 1·7 mm.

Mr. J. Wright (1914 b) records *Ulocrinus* from several other localities in Fife and from horizons "as low as the 2nd Abden and as high as the Upper (Levenseat) Limestone." He does not say whether these are *U. globularis*, and I have not yet seen the specimens.

(8) Muirkirk, Ayrshire. B.M., E 6956. An imperfect cup.

(9) Lower Limestone series, Treame Quarries, Beith, Ayrshire. J. L. Begg Colln., three cups. One of these has only 4 RR and 3 IBB; the small IB is the r. anterior.

(10) Lower Limestone series. Besides Beith, Mr. John Smith (1901) quotes this species as frequent at Dalry.

Measurements of above specimens in millimetres:—

	Height.	Greatest width.	Width at top.
(1) as given by De Koninck,	13·0	12·0	8·0
(2) E 15159,	11·0	9·4	5·8
E 15160,	9·9	9·1	6·3
E 15161,	9·1	9·2	6·2
(3)	12·5	13·6	9·6
(7) E 6324 *a*,	13·1	13·0	7·6
b,	10·4	10·6	7·7
c,	10·8	10·4	7·9
(8)	8·5	7·7	—
Ratio,	100	97	60

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CORRECTIONS TO BATHER, 1912.

pp. 72, 73—For "Horwood, Fife," read "Howwood, near Milliken Park, Renfrewshire."

p. 73, fig. 10—For "r. post. B" read "r. post. R."

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No. XII.—Thomson's Genera of Scottish Carboniferous Corals. By Professor J. W. Gregory, D.Sc., F.R.S., University of Glasgow.

[Read 8th February, 1917.]

[Issued separately, 30th December, 1917.]

The investigation of the rich coral fauna of the Carboniferous rocks of Scotland was the life work of James Thomson, who was one of the pioneers in the use of serial sections in the study of fossil corals (*e.g.*, Thomson, 1882,[1] pl. iii., fig. 2, figures of three out of six serial sections of a "Cyclophyllum"). He developed, moreover, a special method of representing their detailed structure, by which he prepared numerous clear and beautiful plates. He at first collaborated with P. M. Duncan and H. A. Nicholson, but his association with those authorities was unfortunately short.[2] Thomson by his own field work and by gifts from other collectors, notably Mr. R. Dunlop, brought together a magnificent collection of Scottish Carboniferous corals, and he prepared from it many thousands of sections (Thomson, 1883, p. 315, and 1893, p. 675). He described the fauna in a series of some twenty-three papers, in addition to five joint papers with Duncan and Nicholson. His last contribution was a list of Scottish Carboniferous corals, published in 1901, in the "Handbook on the Natural History of the Clyde Basin," prepared for the British Association meeting at Glasgow. This list, which he said was complete, includes thirty-five genera and two hundred and twenty-four species; twelve of the genera and one hundred and sixty-four of the species were founded by him either alone or in association with Nicholson and Duncan. Thomson either independently or conjointly proposed twenty-one new genera and generic names.

Comparatively little reference to Thomson's work on corals

[1] For references see list at the end.

[2] The reason for the abrupt ending of his series of papers with Nicholson may be judged by the remarks in Thomson's paper of 1887, p. 381, footnote, and 1889, pp. 116-127.

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is given in subsequent literature. The genera which he founded in collaboration with Duncan and Nicholson have been generally accepted, but those proposed in his independent papers have been less often mentioned. His great collection was presented to the Kilmarnock Museum, and there destroyed by fire; some of the specimens have been recovered from the ruins, but their special value has been lost. The British Museum contains a few specimens obtained from Thomson in his younger days, but they throw no light on his later work. If he had distributed some of his numerous duplicates to various museums more use could now be made of his work. Fortunately, Hunter, of Lesmahagow, engaged him to name the corals of the Braidwood Collection, part of which is now in the Kelvingrove Museum, Glasgow. Thomson also identified many of the corals in Mr. Dunlop's collection, which is now in the Carnegie Trust Museum at Dunfermline.

Thomson's identifications of the Braidwood corals were apparently hasty, as the names are scribbled in pencil on the backs of the tablets. No attempt was made at specific identification of the great majority of the specimens. There is, for example, a drawerful of *Albertia* in the Kelvingrove Museum, but not one of them is named specifically. Unluckily, moreover, the Braidwood Collection does not, according to Mr. Macnair, contain specimens of the corals, whose identification by Thomson would now be most useful; and some of the generic identifications are inconsistent with his diagnoses. It would be unfair to judge Thomson's work by identifications made hurriedly when away from his books and specimens. So his names on the Braidwood Collection give little help.

The destruction of Thomson's types and slides renders it impossible to check the exactness of his figures. They are very elaborate, but give the impression of being diagrammatic. Mr. Dunlop, who was intimately associated with Thomson, saw him engraving his plates, and prepared many of the photographs on which they were based, remarked that the figures were "merely diagrams." The precision of the figures can be tested by comparison of Ure's specimen of *Fungites*, which is now in the Hunterian Museum, with Thomson's figures of it, and also by comparing a series of photographs made by Mr.

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Dunlop for Thomson with the published illustrations prepared from them. The differences in detail are considerable.

The value of Thomson's species is not here considered. The simple process of rejecting them all—though this proceeding has been suggested—is impracticable. Some have been adopted,[3] and it is most probable that the Scottish Carboniferous corals include more species than had been founded when Thomson began work; and where he described corals not previously named his names should stand.[3]

Dr. Stanley Smith (1913, p. 56) has enumerated a long list of Thomson's species which he regards as varieties of one species; and his opinion of Thomson's descriptive work is indicated by his recommendation that in the absence of the type specimens any critical survey of the species is inadvisable. They cannot be adequately tested until fresh collections are available from the original localities, some of which, however, are closed. The validity of his genera is of greater practical importance, and they may be judged by his descriptions and plates.

The following list enumerates Thomson's genera with their type species:—

Reference Initial.	
	I.—Conjointly with P. M. Duncan.
A. 1867.	*Cyclophyllum bowerbanki* (Ed. & H.), 1867.
	II.—Conjointly with H. A. Nicholson.
D. 1876.	*Koninckophyllum magnificum*, Nich. & Thoms., 1876.
C. 1876.	*Acrophyllum oneidænse* (Billings), 1859.
C. 1876.	*Dibunophyllum muirheadi*, Nich. & Thoms., 1876.
A. 1876.	*Carcinophyllum kersopiana*, Thoms., 1880.
C. 1876.	*Crepidophyllum darchiaci*, Billings, 1860.
D. 1876.	*Thysanophyllum orientale*, Nich. & Thoms., 1876.
1876.	*Lindstromia columnaris*, Nich. & Thoms., 1876
	III.—James Thomson only.
C. 1874.	*Rodophyllum craigianum*,[4] Thoms., 1874.
C. 1875.	*Aspidiophyllum koninckiana*, Thoms., 1875. (Thom. & Nich., 1876, name and fig. only.) (*Aspidophyllum*, Thoms., 1883.)

[3] For example, Prof. Salée (1913, pp. 222 and 245) has recently accepted his *Clisiophyllum subimbricatum* and *Dibunophyllum macchesneyi*.

[4] Thomson altered the spelling of his generic names both intentionally and accidentally. His first spelling is adopted, except when it was obviously a misprint.

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C. 1877. *Kumatiophyllum concentricum*, Thoms., 1877. (*Cymateophyllum*, 1883.)
C. 1878. *Albertia victoriaregia*, Thoms., 1878.
C. 1879. *Histiophyllum ramsayi*, Thoms., 1879.
C. 1880. *Centrephyllum subcentricum*, Thoms., 1880. (Spelt *Centrophyllum* in 1883 and altered to *Centrolamellum* in 1901.)
B. 1880. *Protocyathus verrillii*, Thoms., 1880.
B. 1883. *Protocyathophyllum*.
D. 1883. *Fasciculophyllum dybowski*, Thoms., 1883.
E. 1883. *Centrocellulosum densothecum*, Thoms., 1883.
C. 1883. *Agassizia vesiculara*, Thoms., 1883.
F. 1901. *Asymmetrilamellum lintoni*, Thoms., 1901.

Lindstromia is not a Carboniferous genus. The remaining genera will be considered in the groups indicated by the initial letters A to F in the preceding list.

A.

CYCLOPHYLLUM, *Duncan and Thomson*, 1867. Type species, *bowerbanki* (*Ed. & H.*).—The validity of this genus depends on its distinction from the *Aulophyllum* of Ed. and H. The type of that genus, as mentioned in the original diagnosis, is *Clisiophyllum prolapsum* of M'Coy, 1849, from the Carboniferous Limestone of Derbyshire; that species Edwards and Haime identified with Ure's *Fungites* ("History of Rutherglen," 1793, p. 327, pl. xx., fig. 6). They stated (1850, Brit. Foss. Cor., p. lxx.) that *Aulophyllum* has no columella. Duncan and Thomson accepted the statement, and founded *Cyclophyllum* for species with an essential columella. Their type of *Cyclophyllum* was *A. bowerbanki*, Ed. & H., and they included in *Cyclophyllum* Edwards and Haime's type species of *Aulophyllum*. They admitted in *Aulophyllum* only a new species, *A. edwardsi*. Duncan and Thomson had no right to transfer the type of *Aulophyllum* to *Cyclophyllum* unless they could show that the *Aulophyllum fungites* of Ed. and H. included two species, in which case the *C. prolapsum* of M'Coy would remain as the type of *Aulophyllum*.

Thomson did indeed regard *Fungites* as including two different species, *Aulophyllum fungites*, Ed. & H. (Thomson, 1882, p. 510, pl. iv., fig. 2; 1883, p. 487), and *Cyclophyllum fungites*, Ure (1882, p. 481, pl. ii., fig. 1; 1883, p. 493, pl. xiv., fig. 2).

Ure's original specimen, the type of *Fungites*, is in the Hunterian Museum, Glasgow, and three figures of it have been

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given by Thomson (1882, pl. ii., figs. 1, 1a, and 1b). The specimen shows that Edwards and Haime were quite right as to this species having no essential columella. They described *A. bowerbanki* as differing from *A. fungites* merely by the septa being more numerous and the inner wall wider in proportion to the diameter of the corallum (Brit. Foss. Cor., p. 189). These are specific and not generic distinctions. *Cyclophyllum* can only be retained if its columella be different from that of *Aulophyllum*. Thomson in 1883 says that they both agree in having "a tubular columella" (1883, p. 485); he says (*ibid.*, p. 484) that *Aulophyllum* has a "cylindrical columella," and says the same of *Cyclophyllum* in his diagnosis of that genus (1883, p. 490). He, however, on p. 485 describes the centre of the columella in *Aulophyllum* as consisting of tabulæ, and that of *Cyclophyllum* as consisting of more or less discontinuous lamellæ united by minute vesicular tissue. This difference is illustrated in the sections by Thomson of his *C. bowerbanki* (1883, pl. xiv., fig. 3) and of a young *Aulophyllum* on Fig. 8 of the same plate, but this difference is merely due to the more horizontal growth of dissepiments in the latter, while some tabuliform dissepiments are shown in the upper part of *C. bowerbanki*.

There seems no adequate reason for the subdivision of Edwards and Haime's species *fungites*, and, if so, *Cyclophyllum* is a synonym of *Aulophyllum*.

The identity of *Aulophyllum* and *Cyclophyllum* has been previously adopted by A. Vaughan (1906), by Mr. R. G. Carruthers (1909, p. 149), and, after a detailed investigation, by Dr. Stanley Smith (1913, pp. 55, 56).

Carcinophyllum.—Thomson and Nicholson, 1876 (Annals (4), xviii., pp. 70, 71: first described by Thomson, 1880, p. 242). Type species, *kersopiana*, Thomson, 1880, p. 243, pl. ii., fig. 7, from Arbigland on the Solway. The type species, as shown by Thomson (1883, pl. xii., fig. 9a), has the axial column sharply separated from the outer structures. Its affinities are nearest to *Cyclophyllum* (see, *e.g.*, Thomson, 1883, Pl. XIV., Fig. 4), from which Thomson separated it by the absence of a wall round the axial column, and of an inner cup on the floor of the calice. If there be no cup-like or annular

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elevation on the floor of the calice the genus might be distinguished on that ground; but I am not aware of any specimens which support that view. The main chance of the validity of *Carcinophyllum* rests on the structure of the axial column. It has been adopted for *Clisiophyllids* with thick irregularly contorted anastomosing axial lamellæ, a feature shown in the original figure of the genus, also by (Stuckenberg, 1895, p. 97) Professor Garwood (1912, pp. 556-557) and by Professor Salée (1913, p. 252). Professor Sibly (1906, p. 369, pl. xxxi., fig. 4) and Mr. Douglas (1909, p. 581, pl. xxvii., fig. 5) have both accepted it for corals in which the same structure is indefinitely shown, and further variations are given by Professor Salée (1913, Pl. XI., Figs 1, 2, 3). Thomson described the axial column (1880, p. 241) as having a central median plate surrounded by anastomosing vesicular tissue, as shown in the original figure (Thomson and Nicholson, 1876, No. 2, p. 70). *Carcinophyllum* may be tenable for *Aulophylla*, which have thick anastomosing axial lamellæ; but, if so, *Carcinophyllum delepini* (Salée, 1913, p. 262, pl. xi., fig. 1c), in which the axial lamellæ are radial with fair regularity, is not a member of the genus.

B.

Protocyathus, 1880. Type species, *verrillii*, Thomson, 1880. Possibly owing to the preoccupation of the generic name by Ford in 1878 (Amer. Journ. Sci. (3), xv., p. 124), Thomson in 1883 changed it to Protocyathophyllum. As, in 1901, he included the type of *Protocyathus* in *Protocyathophyllum* he clearly intended the two names to be synonyms. He has published no sections of these corals; they may be young *Zaphrentis*, and Thomson's specimens having been destroyed the genus may be abandoned as indeterminable. Mr. Macnair tells me there is no specimen so named by Thomson in the Braidwood Collection.

C.

Genera Founded on the Axial Column.—Most of Thomson's new genera belong to a group of *Cyathophyllid* corals, of which the oldest established genus is *Clisiophyllum*, founded by Dana, in 1848. In a well-preserved *Cyathophyllum*, which shows the upper surface, such as the *Cyathophyllum stutchburyi*,

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figured by Milne-Edwards and Haime (Brit. Foss. Cor., pl. xxxi., fig. 1), the calice is a sharply defined circular or sub-circular depression above the axial column. In a typical *Cyathophyllum* the calice is flat-floored; but in *Clisiophyllum* the centre of the floor is raised into a boss, which has been called the "calicular boss" or "eminence" and the "columellar boss," and has been regarded as the upper end of a spurious or pseudo-columella. It is similar in character to the raised ring in the calice of the type specimen of *Aulophyllum*.

The Axial Column.—The structure of this axial column is different from that of the outer part of the corallum, and is well shown in many of Thomson's figures. The structure is very variable. It consists essentially of a growth of dissepiments which sometimes expand horizontally, and thus form tabulæ; the intermediate condition forms the "tabellæ" of Dr. Stanley Smith (1916, p. 285). The axial column is traversed by a series of vertical lamellæ, which are sometimes continuous with the septa and sometimes are independent of them. Thomson repeatedly asserted that the structure of this axial column is of the highest value in the classification of these corals. For example, he remarks (1883, p. 309) that the central columellarian area "is of great importance for diagnostic purposes. Indeed, I venture to say that it is in the central area alone we can hope to define accurately either genera or species." In his paper on *Histiophyllum* he says (1879, p. 323) the axial area "is most essential for both generic and specific distinction"; and later he described it (1880, p. 230) as the only structure of classificatory value. On the variations of this axial column he founded most of his genera.

The three most important differences used by Thomson in establishing new genera are the convolution of the central lamellæ, the presence or absence of an essential lamellar columella, and the occurrence or absence of an accessory wall. Thomson's figures indicate that these differences are inconstant and ill-defined. Thomson himself repeatedly referred to the variability of the corals and to the numerous transitional stages by which different genera merge into one another (*e.g.*, 1883, pp. 315-316, 441, 452, 457, 475, &c.; also 1893, pp.

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675-676, 741, 744-745); and he accordingly remarks that their distinction is provisional (1883, p. 314). The convolution of the vertical axial lamellæ was used by Thomson as the special characteristic of *Rodophyllum*. This same feature is shown in other genera. Thus, in his joint papers with Nicholson (Thomson and Nicholson, 1876, Ann. (4), xvii., pl. xxi., figs. 1-4, and pl. xvii., figs. 1-3, and xviii., p. 71, fig. E, and also Thomson, 1883, pl. xiii., fig. 3) this axial convolution is shown in *Clisiophyllum*. It is also shown in *Aspidiophyllum* (Thomson and Nicholson, 1876, Ann. (4), xviii., p. 71, fig. B, and Ann. (4), xvii., pl. xxiii., fig. 2). Thomson has remarked the tendency to this same convolution in *Histiophyllum*, as shown in his figure (1879, pl. ii., fig. 1), and in *Centrophyllum bicentricum*, Thomson (1880, pl. i., fig. 2a). The same feature occurs in many rugose corals, and is analogous to the twisting of the septa into a spiral pseudo-columella, as in the Devonian *Cyathophyllum obtortum*, Ed. & H. (Brit. Foss. Cor., pl. xlix., fig. 7). This torsion of the axial lamellæ or septa is so widespread through the Rugosa and so irregular in its development that it seems of little value as a generic character.

Dr. Stanley Smith has very carefully investigated the structure of the axial column, and says (1913, p. 66) that it is more variable than any other part of the corallum. He has described four types, as seen in transverse section, but they are not sharply defined, and he says that two sections cut from the same coral a short distance apart may be of different designs (1913, p. 67), and that the axial column presents "an endless series of slightly different variations of the same general plan" (p. 68). That conclusion, which seems correct, is opposed to the validity of the genera which Thomson founded on the belief that variations in the axial column are of the highest taxonomic value.

The presence of an essential lamellar columella is asserted for several of Thomson's genera; but the structure so identified is often a compressed hand of dissepiments. Thus Thomson's diagnosis of *Clisiophyllum* says it has a median styliform columella (1883, p. 439); but his figures in the same paper (pl. xiii., figs. 1, 4, and 6) show that the structure so de-

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scribed consists of crowded dissepiments. Similarly he defines *Koninckophyllum* (1883, p. 418) as having "a small compressed columella," but his pl. xi., fig. 2, shows that in *K. retiforme* it consists of only a few dissepiments. Such a structure is not an essential columella, though it may appear so on the surface. Thomson's opinion of this so-called columella varied greatly; thus in the original diagnosis of *Acrophyllum* (Thoms. and Nichs., 1876, vol. xvii., p. 455) he says that the genus has "no columella"; whereas in his paper of 1883 (p. 421) he described it has having a stout lamellar and sometimes bilamellar columella. The genus *Agassizia* was described by Thomson in 1883 as having a double lamellar columella, which would be its most characteristic structure; but as this genus was omitted from his last list he had apparently abandoned faith in its columella.

A true median lamellar plate, which is developed from the counter septum (*e.g.*, Stanley Smith, 1916, p. 231), occurs in some Rugosa, as in *Lonsdaleia*, and is entitled to rank as one variety of columella. It may be regarded as a simple parietal columella.

The accessory wall, which sometimes encloses the axial column, as in *Crepidophyllum*, appears to consist of a special growth of dissepimental tissue, and to be too inconstant to be of generic value. Thomson appears to have attached little value to it in his later years, for though it was used by himself and Nicholson in their definition of *Crepidophyllum*, that genus was omitted from his list of 1901.

It appears therefore that the axial features used by Thomson as generic characteristics are unreliable. It is, however, advisable to consider the genera separately, in the order of their foundation.

Rodophyllum, Thomson, 1874, altered to *Rhodophyllum* in 1876. Type species, *craigianum*, Thoms. This genus was based mainly upon the sub-convolution of the axial lamellæ; but for reasons previously given this feature does not seem of generic value, and I fail to see any valid distinction from *Clisiophyllum*. Lindström (1883, p. 5) has adopted this conclusion. Vaughan (1905, p. 286) regards *Rodophyllum* as a synonym of *Kumatiophyllum*.

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ASPIDIOPHYLLUM, Thomson, 1875, spelt *Aspidophyllum*, 1883. Type species, *koninckiana*, Thoms. The distinctive feature assigned to this genus is the helmet-shaped calicinal boss. It has a median lamella composed of a band of compressed dissepiments. Thomson remarked (1883, p. 464) the strong resemblances of this genus to *Clisiophyllum*, in which the boss is tent shaped. The shape of the boss does not seem an adequate generic character unless the different shapes are the expression of different internal structures; and the differences in structure are non-generic. Lindström (1883, p. 5) correctly included *Aspidophyllum* in *Clisiophyllum*. A. W. Vaughan (1905, p. 282) adopted it as a sub-genus of *Dibunophyllum*.

KUMATIOPHYLLUM, Thomson, 1877, p. 250; spelt also *Kurnatiophyllum* (1875, No. 1, p. 273), *Cymatiophyllum* (1878, p. 166), *Cymateophyllum* (1883, p. 471), and *Cymatophyllum* (1901). Type species, *concentricum*, Thomson (1877, p. 251, pl. i., fig. 1). The name was first mentioned by Thomson, 1875, No. 1, p. 273. Thomson stated (1883, p. 471) that he originally regarded the specimens of this genus as varieties of *Rodophyllum*, and as in some varieties the axial lamellæ are subconvolute, that view seems to me correct. *Kumatiophyllum* may be included in *Clisiophyllum* as a synonym of *Rodophyllum*. Lindström (1883, p. 10) doubtfully adopted this view. Vaughan (1905, p. 285) accepted the genus for corals like *Dibunophyllum*, but without a thick medial plate, and therefore without a crest on the calicular boss.

ALBERTIA, Thomson, 1878. Type species, *victoriaregia*. This genus was founded on a series of large corals in which, according to Thomson's first description (1878, p. 165), the chief distinction from *Aspidophyllum* and *Kumatiophyllum* is that the axial lamellæ in *Albertia* are slightly raised above the inner margin of the primary septa. Thomson remarked that these three genera have a striking similarity in the external and intermediate areas. He describes the calice as being shallow or everted, and having in its centre a series of ridges which converge towards a central depression. Unfortunately none of his figures shows the structure of the calice, which, if correctly described, would justify the genus. It would differ from *Clisiophyllum* by having a central calicular de-

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pression instead of a raised boss. I do not, however, know of any specimen that shows this calicular depression. The internal structure does not show any adequate distinction from *Clisiophyllum*, and Lindström (1883, p. 5) suggests that it is only a specific variation of that genus. Thomson's figure of *Albertia argylli* (1878, pl. i., fig. 2) shows a lamellar pseudo-columella which is composed of crowded dissepiments or tabellæ. Vaughan (1905, p. 286) included *Albertia* in *Kumatiophyllum*.

HISTIOPHYLLUM, Thomson, 1879. Type species, *ramsayi*, Thomson (1879, p. 330, pl. i., fig. 1). This genus has a raised calicular boss, and its chief distinction from *Rodophyllum* appears to be that the axial lamellæ, which are subconvolute in both (Thomson, 1883, p. 459), in *Histiophyllum* are so on the "dorsal side," but not on part of the opposite side (1883, pl. xii., figs. 5 and 6). But the general evidence and Thomson's other figures of the genus show that this feature is too variable to be of generic value (*e.g.*, 1879, pl. ii., figs. 4, 5, 8; pl. iii., fig. 3).

Thomson remarked that the relations of *Histiophyllum* to *Rodophyllum* and *Aspidiophyllum* appear "so natural and intimate" that he long hesitated to create the genus (1883, p. 458); he also says that the boundary line between these three genera is very difficult to define (p. 459). It seems clear that *Histiophyllum* is a synonym of *Rodophyllum*, and therefore of *Clisiophyllum*.

CENTROPHYLLUM, Thomson, 1880 (p. 227), then spelt *Centrephyllum*; 1883 (p. 467). Type species, *subcentricum*, Thomson (1880, p. 230, pl. i., fig. 1). The genus is described as very similar to *Kumatiophyllum*, some specimens of which Thomson regarded as varieties of *Centrophyllum*. Of the differences he mentions (1883, p. 468) the most important is that in *Kumatiophyllum* the axial ridges are sinuous (as *e.g.*, in 1877, pl. i., figs. 2 and 3), while in *Centrophyllum* they are straighter (as in 1880, vol. xii., pl. i., fig. 4); but this difference cannot be retained as of generic value. *Centrophyllum* has a slightly elevated dome-shaped boss, which is formed of variable ridges on the floor of the calice. It represents therefore an intermediate stage between *Albertia* and

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the rest of this group. Thomson remarked (1883, p. 468) the close resemblance in external character to *Clisiophyllum*, and that he long referred some varieties of *Centrophyllum* to *Kumatiophyllum* owing to their natural and intimate relationship. He says (1883, p. 469) that in each of these genera "there are central types which are separable from the nearest allies by their structural details, which are of a diverse character, and which merge and unite their nearest allies by extremely minute gradations." The genus seems to be practically the same as *Kumatiophyllum*, of which it was regarded as a synonym by Vaughan (1905, p. 286), and must share the fate of that genus. Professor Lindström (1883, p. 7) doubtfully, and Professor Salée (1913, pp. 192-201) have previously treated it as a synonym of *Clisiophyllum*.

Centrolamellum, Thomson (1901, p. 484), is an alteration of the name *Centrophyllum*. The first species included in it is the type of *Centrophyllum*.

Agassizia, Thomson, 1883. Type species, *vesiculara*, Thoms., 1883. This generic name was preoccupied by Valenciennes in 1846 for an echinoid, so if Thomson's genus were valid it would have to be renamed. In 1883 Thomson described it as quite unlike any of the other corals and as broadly separated from all known genera. Apparently the essential character is that some of the primary septa are attached to a fusiform stout plate in the centre of the calice. He said also that the septa are stout and vesicular, a feature to which he possibly attached much value as the type species was named *vesiculara*. His list of 1901 omits the name *Agassizia*, but includes a species, *Clisiophyllum vesicularum*. It seems therefore that Thomson abandoned the genus and included the only species in *Clisiophyllum*. It is true that the original specimen of *Agassizia vesiculara* came from Charleston, in Fife, and the *C. vesicularum* of 1901 from Langside, Beith; but this does not indicate their specific distinction, as in the 1901 list only one locality is given for the great majority of the species.

The single section of *Agassizia* figured by Thomson when he founded the genus (1883, pl. iv., fig. 9) shows that some of the septa are continued to the centre, and join a double lamellar

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columella. If that figure be correct the genus would be distinct from *Clisiophyllum*, but his action in 1901 suggests that his figure is not reliable. His final inclusion of *Agassizia*, which he said has no calicular boss, in *Clisiophyllum* shows that Thomson did not always rely upon that feature.

ACROPHYLLUM, Thomson and Nicholson, 1876 (Ann. (4), xvii., p. 455). Type species, *oneidænse* (Billings). (Non Thomson, 1883, pp. 421-426.) This genus in the original foundation is described as having no columella; whereas later Thomson (1883, p. 421) said it had a stout more or less bilamellar columella. A stout median plate opposite the fossula is clearly figured in his illustration, 1883, pl. xi., figs. 9 to 15. Unluckily, however, the coral identified by Thomson as *Axophyllum* from Charleston (figured 1883, pl. xi., figs. 10 and 11) has no columella, whereas, according to Milne-Edwards and Haime, that was one of its essential characters. It would appear, then, that the species referred to *Acrophyllum* by Thomson in 1883 belong to *Axophyllum*, and that *Acrophyllum* depends on the original diagnosis of 1876. Grabau and Shimer (1909, p. 60) retain *Acrophyllum* on the grounds of its tent-shaped boss and twisted septal ends, of which the former is the essential and the latter one of the occasional characters of *Clisiophyllum*. In the type species *A. oneidænse* the tabulæ are much better defined, stouter, and more distant than in *Clisiophyllum*, and the genus appears valid. The type species is from the upper Helderberg or lower Devonian of Canada.

Vaughan (1905, p. 281) divided the genus between *Koninckophyllum* and *Axophyllum*.

DIBUNOPHYLLUM, 1876, Thomson and Nicholson (1876, p. 457). Type species, *muirheadi*, Nich. & Thom., 1876 (in Ann. (4), xvii., p. 462, pl. xxiv., fig. 3, and pl. xxv., figs. 4 and 5). This genus is closely related to *Clisiophyllum*. According to Thomson in 1883 the two genera differ mainly by the shape of the boss, which in *Clisiophyllum* is tent-shaped or conical (1883, p. 437), and in *Dibunophyllum* is low and rounded. This feature seems inadequate, and, as remarked by Professor A. Salée (1913, p. 234), the validity of *Dibunophyllum* depends on the nature of the median plate which

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bisects the calicular boss and underlying axial column. Thomson's figure, 1883, pl. xii., fig. 3 (reproduced from the Annals (4), xvii., pl. xxv., fig. 7), of a specimen from Charleston not specifically identified, has a well-developed median plate; but in the two species, *D. splendens*, Nich. & Thom., and *D. macchesneyi*, Nich. & Thom. (Ann., xvii., pl. xxv., figs. 1 and 3, reproduced in 1883 as pl. xii., figs. 1 and 2a), the median band is shown to be constituted by a series of dissepiments. *D. splendens* no doubt has a thin central lamella; but there seems no real difference in this respect between it and the *Clisiophyllum bipartitum* and *C. oblongum*, as shown in Thomson's figures, 1883, pl. xiii., figs. 1 and 2. *Dibunophyllum splendens* and *D. macchesneyi* seem generically indistinguishable from *Clisiophyllum;* but if the unnamed *Dibunophyllum* (Ann. (4), xvii., pl. xxv., fig. 7, and 1883, pl. xii., fig. 3) be correctly shown it would belong to the genus as it is usually interpreted.

Strictly the type species of the genus is *D. muirheadi* from Gateshead, Beith, and its figure in the Annals (4), xvii., pl. xxv., fig. 4, represents it as having a composite dissepimental median band; and if so it should be included in *Clisiophyllum*.

The question as to which species is the type of *Dibunophyllum* is a little confused owing to the approximately simultaneous publication of two papers, one by "Thomson and Nicholson" in the Annals in June, 1876, the other by "Nicholson and Thomson," read before the Philosophical Society of Glasgow in March, and published later the same year. *Dibunophyllum* was diagnosed in the Annals, but no species were mentioned in the text, though their names are given in the explanation of the plates. The species date from the Philosophical Society paper. The first mentioned there is *D. muirheadi*, and it has been traditionally used as the type. Its two founders were obviously somewhat uncertain as to its delimitation, as the specimen figured on pl. ii., figs. 2 and 2a, of the Glasgow paper as *D. muirheadi* appears in the Annals as a young *Dibunophyllum*, and the figure in the Annals, pl. xxv., fig. 1, referred to as "sp.," is determined in the Glasgow paper, pl. ii., fig. 1, as *D. splendens*.

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Either the figure in the Glasgow paper, pl. ii., fig. 3, described as a transverse section of a typical example of *D. muirheadi*, or the earlier published figure of that species in the Annals, pl. xxiv., fig. 3, is the type figure of the species. The illustration in the Glasgow paper (pl. ii., fig. 3) shows a median band, which on careful inspection proves to be a composite structure, and not a compact lamina; the lower end is bilaminar, and consists of four pairs of tabellæ; then follows a short single thin line, which forks around two intertabellar spaces; and finally in the upper part are a few closely compressed intertabellar spaces, the walls of which are continued upward by a single thin lamella. A similar composite tabellar or dissepimental structure is shown for the median band in the Annals, pl. xxv., fig. 5, which is, however, referred to *D. muirheadi* with a note of interrogation.

The first figured *D. muirheadi*, that in the Annals paper, pl. xxiv., fig. 3, similarly has no true "columellarian" line, but a series of dissepiments or tabellæ, traversed by a thin irregular line, which subdivides into two dissepiments just below the centre.

Dibunophyllum has been recently accepted by A. Vaughan (1905, p. 283), according to whom it includes *Clisiophyllids*, in which the mesial plate extends nearly across the central area, and is continued as a prominent lamella into the fossula. He remarks that "the distinction . . . is only one of degree." Professor A. Salée has followed the same course. He clearly defines the "veritable lame columellaire," which he shows in his pls. viii. and ix., and says that its absence from *Clisiophyllum* is the distinction between that genus and *Dibunophyllum* (1913, p. 234). He admits the existence in some species of *Clisiophyllum* of "petites plaques axiales, mais ces plaques sont discontinues et ne forment pas une lame se poursuivant à travers les divers especes intertabulaires." According to these definitions Thomson's figures show that *D. muirheadi* is a *Clisiophyllum*,[5] and the original diagnosis by Thomson and Nicholson agrees with the figures. It states

[5] Mr. Carruthers remarks, 1910, p. 172, "The Dibunophylla are not widely differentiated from many of the Clisiophyllids. . . ."

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(1876, Ann. (4) xvii., p. 458) that the axial column of *Dibunophyllum* is "intersected by several incomplete columellarian lines, or *rarely by one such line*"; it continues that the central area is divided by "a median lamina," which Thomson therefore distinguished from the "columellarian lines." In the original *D. muirheadi* there is no distinct median lamina, and Thomson and Nicholson say that the occurrence of a single columellarian line is rare; so that to adopt *Dibunophyllum* as characterised by a lamellar columella is clearly opposed to the original intention of Thomson and Nicholson, and to Thomson's later action in putting *D. muirheadi* first among the species.

Lindström (1883, p. 9) doubtfully referred the genus to *Clisiophyllum*.

The close affinity of *Dibunophyllum* to others of Thomson's *Clisiophyllid* genera is also remarked by Sherzer (1891, p. 294). He says that *Dibunophyllum*, *Aspidophyllum*, *Rodophyllum*, *Cymateophyllum*, *Centrophyllum*, *Histiophyllum*, and *Albertia* are very closely related to *Clisiophyllum*, and are separable only by closest attention to the details of the central area.

Dibunophyllum has, however, been accepted by several authors, including Dr. A. Vaughan (*e.g.*, 1905, p. 282), Professor T. F. Sibly (1908, p. 74), Mr. J. A. Douglas (1909, p. 581), Mr. R. G. Carruthers (1910, p. 171), and Professor E. J. Garwood (1912, p. 474); Dr. Stanley Smith (1916), who transferred to it the *Lonsdaleia rugosa* of M'Coy, and showed that the median lamina is septal; and also by Professor A. Salée (1913) and Stuckenberg (1895, p. 94, and 1904, p. 54).

The genus has, moreover, become one of the zone fossils of the Carboniferous Limestone, so its abandonment would be inconvenient. If the coral to which Thomson gave no specific name be accepted as the type and included in *D. muirheadi*, the genus (Ann. (4), xvii., pl. xxv., fig. 7) can be retained with the interpretation adopted by the above-mentioned authors. This course is a strain on the laws of nomenclature, but the abandonment of *Dibunophyllum* would lead to so much trouble that its retention by this device would be convenient.

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CREPIDOPHYLLUM, Nicholson and Thomson, 1876 (Proc. R. Soc., Edin., vol. ix., p. 149). Type species, *archiaci* (Billings), from Devonian, Canada. This genus has been regarded as a synonym of the *Craspedophyllum* of Dybowski (1873, p. 160), and as closely related to *Heliophyllum*. The affinities of the three may be contrasted as follows:—

Heliophyllum—Corallum simple; no inner wall; septa carinate; t. = halli, Ed. & H.

Craspedophyllum—Corallum simple; an inner wall around a central tabulate tube; septa carinate; t. = americanum, Dybowski (1873, p. 155, pl. vi., figs. 1 and 6).

Crepidophyllum—Corallum compound; an inner wall around a central tabulate tube; septa carinate; t. = archiaci, Billings.

Grabau and Shimer and others have included *Crepidophyllum* in *Craspedophyllum*. To keep simple and compound corals in distinct subgenera is a convenient and often a valid course. Unless it be adopted here *Crepidophyllum* must be dismissed as a synonym of *Craspedophyllum*.

Heliophyllum and its type species, it may be remarked, have been included by Lambe (1901, pp. 133, 148) in *Cyathophyllum*.

D.

KONINCKOPHYLLUM, Thom. & Nich., 1876. Type species, *magnificum*, Thom. & Nich., 1876 (Thomson, 1883, pl. xi., fig. 1, quoted as type, p. 419). This coral has a massive fasciculate corallum, and although in the original description it was used to include simple and compound corals, it may be regarded as a compound *Clisiophyllum*. Thomson states that the columella is styliform, and also that it is median and compressed, and divides the central area into halves (1883, p. 418). It appears to have the structure typical of the *Clisiophyllids*. Carruthers (1913, p. 52) has merged *Koninckophyllum* in *Lophophyllum*, but the two genera seem to me distinguished, as *Lophophyllum* has no axial column, no vertical axial lamellæ, and has a septal columella.

Professor Sibly (1908, p. 70) has adopted *Koninckophyllum*, and includes in it a simple coral; and the maintenance of the

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genus for compound forms only is no doubt logically unsound in this group; but the only apparently valid ground for its retention is as a convenient subgenus for the fasciculate *Clisiophyllids*. Vaughan perhaps regarded it as such when he adopted it (1905, p. 281) for corals allied to *Lithostrotion* and with a *Clisiophyllid* tendency.

E.

Thomson described a series of small, simple corals, which he referred to the genus *Densyphyllum*[6] of Dybowski and to new genera of his own, *Fasciculophyllum* and *Centrocellulosum*. These three groups may be included in one genus, except that Thomson's *F. magnificum* (1883, p. 450, pl. iv., fig. 10) clearly belongs to quite a different group, and if correctly figured may belong to Stuckenberg's genus *Humboltia*. The corals which Thomson referred to *Densyphyllum* do not appear to belong to that genus; its characteristic features are that the tabulæ are confined to a central area which is enclosed by a dense outer zone that is described as filled with structureless sclerenchyma (Dybowski, 1874, p. 392). The major septa, however, extend through the tabulæ to the centre, where they are separate; and Dybowski stated (p. 335), as one of the chief essential characteristics, that the coral has no false columella. The wide undulating tabulæ crossing the large central space are clearly shown in Dybowski's figure, pl. ii., fig. 2a. There is no indication in Dybowski's figure of a fossula—though its presence is stated in the text—nor of any dissepimental endotheca. The corals which Thomson referred to (*Densyphyllum*) are very different. He describes the septa as coming together and sometimes coalescing at the centre. His genus, *Fasciculophyllum*, was, in fact, founded on the fasciculate arrangement of the inner ends of the septa "in the typical forms." He says the septa may form a more or less reticular structure in the centre of the corallum (p. 448). An axial fascicular or reticular structure due to the fusion of the inner ends of the septa is a false columella. A more important difference is the absence of the structureless sclerenchymatous outer zone of *Densyphyllum*.

[6] Lindstrom (1883) has suggested for this genus the name *Pycnophyllum* on philological considerations.

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Thomson has recognised the resemblances of these corals to *Zaphrentis*, which he distinguishes by the inner ends of the septa being folded round as the wall of the septal fossula. In *Densyphyllum* he says that the septa are in no instance folded round to form the wall of the fossula. This arrangement is not well developed in young Zaphrentids. There is nothing of the sort, for example, shown in Thomson's figure of *Zaphrentis centralis* (1883, pl. vi., fig. 8). The corals assigned by Thomson to the three genera may be all young *Zaphrentis*.

The references to these genera are as follows:—

FASCICULOPHYLLUM, Thomson, 1883. Type species, *dybowski*, Thomson (1883, p. 449, pl. vi., fig. 23). The name does not appear in his 1901 list, in which the only species *dybowski* is a *Cyathaxonia*. His type species appears to be a young *Zaphrentis* and his *F. magnificum* (1883, p. 450, pl. iv., fig. 10) is probably a *Humboltia*.

CENTROCELLULOSUM, Thomson, 1883, p. 452. Type species, *densothecum*, Thomson, 1883, p. 453, pl. x., figs. 7 and 9. The name was omitted from his list in 1901. He remarked, in 1883, that it has intimate relations to *Carcinophyllum*, and that there is "a mergence from *Fasciculophyllum* into the genus *Centrocellulosum* (1883, p. 452). It seems to me to fall with that genus. The omission of the genus from Thomson's complete list of 1901 may indicate that he had recognised its invalidity. The name *Centrocellulosum* appears in that list only as a species of *Clisiophyllum;* but a specimen in Mr. Dunlop's collection that was named *Clisiophyllum centrocellulosum* by Thomson shows that this species has nothing to do with his genus of the same name.

F.

ASYMMETRILAMELLUM, Thomson, 1901, p. 483. Type species, *lintoni*. This name appears in the list of 1901 for a species from Kilmarnock Water, but it has not been described, and may be treated as a *nomen nudum*.

G.

THYSANOPHYLLUM, Nich. & Thom., 1876 (Proc. R. Soc., Edin., vol. ix., p. 150). Type species, *T. orientale*, Nich. & Thom.

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This is a compound coral which has many strong resemblances to *Lonsdaleia*. The difference, according to Thomson, is that *Lonsdaleia* has a linear columella, while *Thysanophyllum* has none; but Thomson's best figure of *Thysanophyllum* shows a gap in the centre of the section from which something has been lost. *Thysanophyllum* may be only a *Lonsdaleia* in which the central part of the corallite has been broken away. The genus has been adopted by Carruthers and Stanley Smith as probably or possibly the ancestral form of *Lonsdaleia*, to which they admit its close resemblance. It has a somewhat simpler structure than *Lonsdaleia*, and may be tenable as a subgenus.

Summary of Conclusions.

It seems to me therefore that Thomson's genera, *Rodophyllum*, *Aspidiophyllum*, *Acrophyllum* (in part—Th. & N., non Thomson, 1883), *Histiophyllum*, *Dibunophyllum* (in part), *Kumatophyllum*, *Agassizia*, *Centrophyllum*, *Centrolamellum*, and probably also *Albertia*, are all variations of one common Carboniferous type, which was first recognised and described by Dana as *Clisiophyllum*, and they should all be included in that genus.

That *Koninckophyllum* is a fasciculate coral of the same type.

That *Fasciculophyllum* and *Centrocellulosum* are young *Zaphrentids*.

That the name *Agassizia* was preoccupied, and Thomson himself abandoned it.

That *Protocyathophyllum* is at present indeterminable.

That *Thysanophyllum* is invalid as founded, but may be tenable as a subgenus of *Lonsdaleia*.

That *Crepidophyllum* is a subgenus or synonym of the *Craspedophyllum* of Dybowski.

That *Cyclophyllum* is a synonym of *Aulophyllum*, and *Carcinophyllum* is closely allied to it.

One object of this communication is to stimulate the re-collecting of corals at Thomson's type localities in order to see which of his species should be maintained.

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No. XIII.—The Igneous Geology of the Cumbrae Islands, Firth of Clyde. By G. W. Tyrrell, A.R.C.Sc., F.G.S., Lecturer in Mineralogy and Petrology, Glasgow University.

[Read 8th March, 1917.]

[Issued separately, 13th February, 1918.]

Introduction.

The picturesque and conspicuous Cumbrae Islands, in the Firth of Clyde, have often been mentioned in geological literature, and many of their geological features and a few of their igneous rocks described; but there has never been a comprehensive statement of the characters and relations of the igneous suite as a whole in connection with the great Clyde Carboniferous lava-plateau of which it forms a part. Sir A. Geikie (1897, pp. 368-9, 385, 407-8) makes repeated references to the igneous phenomena displayed in these islands, and gives an excellent sketch of the Little Cumbrae, showing its fine regular lava escarpments. In regard to the characters and ages of the several groups of dykes (and sills) in the Great Cumbrae he follows the work of W. Gunn (1903), which was published later in a Survey memoir. Gunn distinguished four groups of dykes—(1) Trachyte (and bostonite), having a general E.N.E. direction; (2) porphyritic basalt, trending in the same direction; (3) E.W. dolerite dykes; and (4) N.N.W. dykes, probably of Tertiary age (Gunn, 1903, pp. 61-2). These are arranged in order of age, but we shall have reason later to question the general priority of the trachytes and bostonites. A few petrographical details are given in an appendix to the memoir (pp. 177-8). In these *Transactions* Mr. James Neilson has contributed a short paper on the Little Cumbrae and its minerals (1893), and Mr. John Smith has described the remarkable flow structure in a felsite dyke north of Downcraig Ferry in the Great Cumbrae (1902).

The Cumbraes consist of two islands, the Great and the Little Cumbrae, situated in the Firth of Clyde between Fairlie

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and south Bute. The nearest point on the Great Cumbrae, Keppel Pier, is only 2 miles from Fairlie. The Great Cumbrae is a pear-shaped island, with the narrow stalk towards the north, and the deep depression of Millport Bay occupying the broad southern end. Its greatest length, from north to south, is about 3½ miles; and the greatest breadth, near Millport, about 2 miles. The Little Cumbrae is similarly shaped, but is elongated towards the north-east. It is 1½ miles long in this direction, and about 1 mile wide. The highest point on the Great Cumbrae, near the centre of the island, is called the Glaid Stone, and is 417 feet above sea-level. The tower (Old Lighthouse) on the Little Cumbrae stands on the eighth lava flow at a height of 408 feet above sea-level.

The larger portion of the Great Cumbrae consists of red sandstones and conglomerates belonging to the Upper Old Red Sandstone, but about Millport Bay there is a small area underlain by rocks belonging to the Calciferous Sandstone.[1] A strong N.S. fault, with a throw of 1000 feet to the west, traverses the island, and emerges near the eastern side of Millport Bay. The whole island is ribbed and reticulated with numerous dykes, sills, and bosses of igneous rock, which roughen and diversify its surface.

The Little Cumbrae consists almost entirely of basalt lavas of Calciferous Sandstone age. On the eastern side at the base of the lavas there are one or two intercalations of sediments; and coarse volcanic agglomerate in impersistent layers has been reported from the north-east coast (Gunn, 1903, p. 59). The island is remarkable for its fine terracing due to the weathering of the basalt lavas of which it is composed (Sir A. Geikie, 1897, p. 368).

Classification of the Igneous Rocks.

The classification of the igneous rocks of the Cumbraes adopted here is based upon a fairly exhaustive examination of their field characters and relations, and differs from that put forward by Gunn principally in the relative ages assigned to the Carboniferous basalts and trachytes.

[1] See one-inch scale map, sheet 21, *Geological Survey of Scotland* (1901).

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I. Calciferous Sandstone.
   (*a*) Basalt lavas of the Little Cumbrae.
   (*b*) Basaltic vents (probably also some of the bostonite intrusions).
   (*c*) E.N.E. dykes of porphyritic basalts (Markle and Dunsapie types).
   (*d*) E.N.E. dykes and sills of bostonite and felsite.
   (*e*) A small series of non-porphyritic (Jedburgh) basalt dykes, with north-east trend.

II. Permo-Carboniferous (?)—E.W. dykes of quartz-dolerite.

III. Tertiary.
   (*a*) Ophitic olivine-dolerite and crinanite.
   (*b*) N.W. dykes of Cumbrae type (cumbraite).
   (*c*) Dykes of tholeiite (Brunton type).

The relative ages of the three main groups may be regarded as well-established by the evidence which will be given later; but there is still some dubiety as to the age relations of the minor divisions of the Calciferous Sandstone and Tertiary groups. The order given above is correct, so far as the meagre evidence goes. The basalt lavas of the Little Cumbrae and the basaltic vents of the Great Cumbrae are probably contemporaneous. There can also be but little doubt that the majority of the bostonite and felsite dykes are later than the basaltic phase, although possibly not much later. It is probable that the periods of intrusion of the different groups overlapped, so that apparently contradictory age relations may have been established. The E.W. dykes are so placed on the list because of their identity in petrographic character and similarity of direction to the well-known E.W. dykes of Central Scotland, which are most generally regarded as of late Carboniferous age. Moreover, one of the Cumbrae quartz-dolerites appears to be deflected from its course by an E.N.E. basalt dyke which it encounters (see p. 257).

Field Relations.

1. The Calciferous Sandstone suite.
   (*a*) The basalt lavas of the Little Cumbrae.

The Little Cumbrae is built of a succession of basalt lava

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flows, each of which forms a well-defined crag and flat, giving rise to the characteristic terracing. The beds are bent into a flat syncline, the axis of which runs in a N.N.W. to S.S.E. direction. Viewed, however, from the west, as from south Bute, the lava terraces have a distinct anticlinal arrangement, which suggests that the western limb of the syncline is itself bent into a fold, the axis of which runs at right angles to that of the synclinal axis. Gunn estimates the aggregate thickness of the lavas as between 600 and 800 feet (1903, p. 59). On the eastern side of the island white sandstones can be seen at the base of the lavas. Two thin basalt flows, building the small Castle and Trail Islands, are intercalated with the sandstone. Gunn has also reported volcanic agglomerate with fragments reaching 1 foot in length on the north-east shore, but these fragmental rocks are impersistent and of no great thickness. A traverse from the farm on the east coast of the island to the tower on the summit, over the long eastern limb of the syncline, shows that the main mass is composed of eight distinct flows. The average thickness of the flows must therefore be between 75 and 100 feet. Nos. 1, 5, and 8, counting from the base, are very thick.

The rocks are basalts of the felspathic types so common in most parts of the Clyde Plateau. They are massive, hard, and completely crystalline in their central portions (from whence the specimens used in their petrographical determination were taken), but become slaggy and amygdaloidal towards the upper and lower parts of the flows. Mr. Neilson records analcite, white stilbite and red heulandite among the minerals found in the cavities. He also found large cavities lined with a milky variety of quartz to a depth of 1 or 2 inches (1893, p. 373). The sequence of the flows is as follows:—

No. 8—Basaltic mugearite, passing into Markle basalt.
No. 7—Mugearite.
No. 6—Mugearite.
No. 5—Markle-Jedburgh basalt.
No. 4—Markle-Jedburgh basalt.
No. 3—Markle-Jedburgh basalt.
No. 2—Basaltic mugearite.
No. 1—Markle basalt.

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(*b*) Basaltic vents (probably also some of the bostonite intrusions).

The rather numerous little basaltic plugs and vents in the Great Cumbrae do not appear to have hitherto been recorded, save one or two on sheet 21 of the 1-inch scale map of the Geological Survey of Scotland. With them may be associated some composite intrusions of bostonite and basalt, and one or two bostonite sills and plugs. These are all united by the fact that they are cut by the E.N.E. dykes of porphyritic basalt; but, as shown later, some of the bostonite sills and dykes are clearly later than this group. Five basaltic vents and plugs have been found at Bell Craig, Skate Point, the Manse, Nupkur Point, and ¼ mile N.N.W. of the Lion Rock.

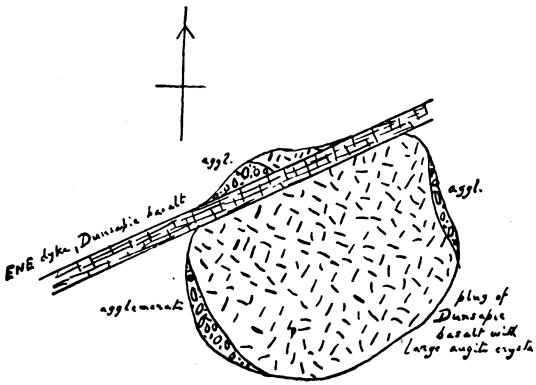

Fig. 1.—Plan of Vent at Bell Craig, Great Cumbrae.

Bell Craig is situated in the cliff at the back of the raised beach on the west coast of the island, about ½ mile west of Figgatoch. It consists of an almost circular boss, standing out prominently with vertical rock faces, in front of the main cliff. The plan (Fig. 1) shows the relations of the component rocks. It consists almost entirely of an intrusion of Dunsapie basalt rich in phenocrysts of a black augite, which sometimes reach a length of 3 inches. In three places around the margin of the vent a little agglomerate may be seen. A deep cleft in the vent is caused by the weathering of an E.N.E. dyke of Dunsapie basalt, which may be traced down to the shore close

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by. The vent has a vertical contact with Old Red Sandstone conglomerate, as can be seen on the northern side. At this contact the Dunsapie basalt plug has caught up numerous fragments of sandstone and quartz from the Old Red Sandstone. The greatest width of the vent is about 50 yards.

Skate Point is on the west coast about $\frac{2}{3}$ of a mile north of Bell Craig. It is occupied by a small boss of Jedburgh basalt, which is covered at high tide. It has a sinuous vertical boundary against baked sediments, which stand up in a low wall on the landward side. From this margin to the sea the plug measures about 50 yards in diameter.

The Manse.—This intrusion occurs in the field behind the Manse, about $\frac{1}{2}$ mile N.W. of Millport Pier. It has a boss-like form somewhat elongated in a north-easterly direction. Its length is about 100 yards, the greatest breadth 30 yards. The rock is a somewhat decomposed Markle basalt.

Nupkur Point.—A little mass of light-coloured Jedburgh basalt (marked as bostonite in the Survey map) occurs at Nupkur Point west of Millport Bay. It is elliptical in shape, and is elongated towards the E.N.E. It probably also includes the island of the Clach, which is a little mass of igneous rock.

Quarter Mile N.W. of the Lion Rock.—A small intrusion occurs here of a porphyritic basalt intermediate between the Markle and Dunsapie types. It is pear-shaped, and extended from east to west, with a greatest length of about 50 yards and a width of 40 yards. The rock has caught up numerous xenoliths of sandstone and baked them into quartzite.

Sheughends, Play Hill, and Terrach Hill.—A group of four intrusions, composed partly of bostonite and partly of basalt, forms a little range of steep, rugged hills extending in a north-easterly direction about 1 mile north of Millport. The two south-western masses, Sheughends and Play Hill, are composite intrusions, consisting of porphyritic basalt (Markle) on the northern edge, the remaining and larger portions being bostonite. These are of boss-like character, and are elongated in a north-easterly direction (Fig. 2). The relations of the basalt and bostonite are not very clear; but on Sheughends the bostonite can be traced to within 6 inches of the basalt, both rocks preserving their special characters up to the junction. It

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is probable that the basalt was the earlier intrusion, and that the bostonite was intruded later, leaving the basalt adhering to the margin of the vent. Sheughends is about 300 yards in length by 60 yards in width, and Play Hill about 150 yards in length by 60 yards in width. These intrusions have a close resemblance to those of the Knockside Hills, near Largs (Wilson, 1916, p. 88).

To the north of Sheughends is a small boss of bostonite of about the same size as Play Hill. It is cut both by porphyritic E.N.E. basalt dykes and by an E.W. dyke.

The range is extended towards the north-east by a long,

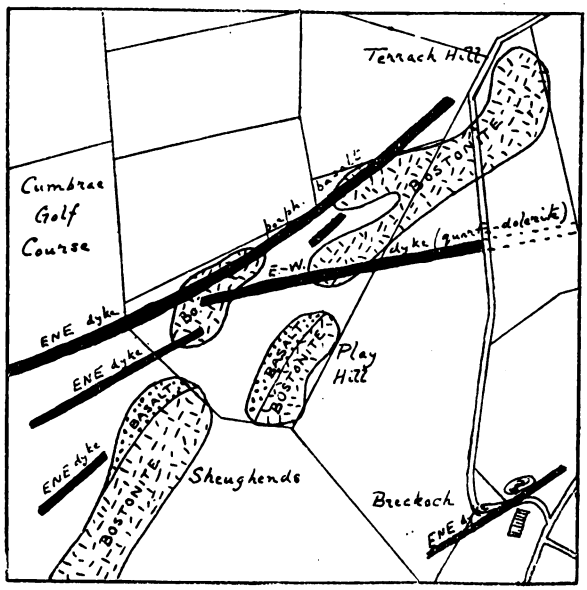

Fig. 2.—Sketch Map of the intrusions of Sheughends, Play Hill and Terrach Hill, Great Cumbrae.

irregularly shaped mass of bostonite, which may be composed of two or more contiguous intrusions. It is well exposed in a small quarry at Terrach Hill by the side of the road leading to the interior of the island. The mass is about 500 yards in length by a greatest width of 90 yards. It is cut by the porphyritic E.N.E. dykes and by an E.W. dyke. A thin sill

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of a platy-weathering trachytic rock may be traced through the plantation west of Terrach Hill.

(*c*) E.N.E. dykes of porphyritic basalt.

These dykes are very numerous throughout the Great Cumbrae, cutting the Upper Old Red Sandstone and the Calciferous Sandstone alike; but only two or three are found cutting the basalt lavas of the Little Cumbrae. The direction is most generally E.N.E., but it may vary between this and due north-east. The dykes are well exposed on the shores of the island, but may frequently be traced inland, and attain occasionally the length of a mile. The thickness is variable, ranging from 3 feet to about 40 feet. A basalt dyke (Markle type) at Lady Bay is 37 feet thick, but the average thickness of the dykes of this group is about 12 feet. Their attitude is generally vertical; but a few hade a little east of south, and one near Doughend Hole has an inclination of 45 degrees from the vertical.

A few details may be given of some of these dykes, starting from the south-western corner and proceeding in a clockwise direction around the island. Near Doughend Hole there is a group of porphyritic E.N.E. dykes which hade east of south. The thickness of the long dyke which strikes inland by Westburn House is 12 feet. These dykes are all highly porphyritic basalts belonging to the Markle and Dunsapie types. A N.N.W. Tertiary dyke cuts the whole series.

Craignan Fitheach.—On the western shore, opposite Craignan Fitheach, is the section cited by Mr. Gunn as proving the posteriority of the E.N.E. basalts to the bostonites (1903, p. 62). A detailed examination of the section, however, reverses this conclusion. There are four distinct intrusions (see Fig. 3). Starting from the south, the first is a thick dyke-like mass of porphyritic bostonite, which becomes distinctly denser against the succeeding rock. The latter is a blue porphyritic basalt (Dunsapie type), which is in contact with the bostonite along most of its length. At some points, however, thin lenticular strips of hardened sandstone, up to 6 inches in width, intervene between the two intrusions. The margin of the basalt is decomposed, and does not afford any evidence as

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to its posteriority or otherwise to the bostonite. Following the basalt, to the north, is another mass of porphyritic bostonite, but interposed between the two is a thin but constant band of quartz-conglomerate and sandstone, from 12 to 18 inches in thickness. The bostonite shows a cooled margin against this band. From these observations it appears more probable that the basalt dyke rather than the bostonite is the earlier intrusion. The whole series is cut across by a thin dyke of N.W. direction and Tertiary age.

The two bostonites and the porphyritic basalt may be traced from the shore up into the crag (Craignan Fitheach), at the

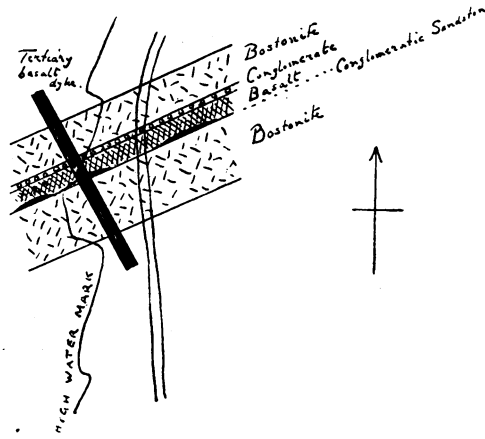

Fig. 3.—Plan of Basalt and Bastonite Dykes at Craignan Fitheach, Great Cumbrae.

back of the raised beach. As this cliff is followed to the north-east it gradually traverses the line of strike of the dykes. Consequently there is seen successively the southern bostonite, the basalt dyke, the northern bostonite, and finally the Upper Old Red Sandstone, forming the face of the cliff. The southern bostonite diverges to the east on the top of the cliff, and forms the line of crag known as the Kamelet. The basalt dyke can be traced to the "hairpin bend" of the field path by the Targets, but the northern bostonite is seen no farther than the north-east end of Craignan Fitheach.

Numerous E.N.E. porphyritic basalt dykes occur near

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Sheriff's Port. North of the Clate Rock (a Tertiary N.W. dyke) there is an E.N.E. dyke, 15 feet in thickness, which shows a concentration of phenocrysts towards the centre of the dyke, forming a Markle basalt, the margins being a non-porphyritic Jedburgh basalt. It is cut by the Clate Rock dyke.

The E.N.E. dykes are comparatively sparse between Fintray Bay and the north end of the island. From the latter point to Downcraig Ferry, on the eastern shore, they are very numerous. Mr. Gunn records over forty in half a mile of coast-

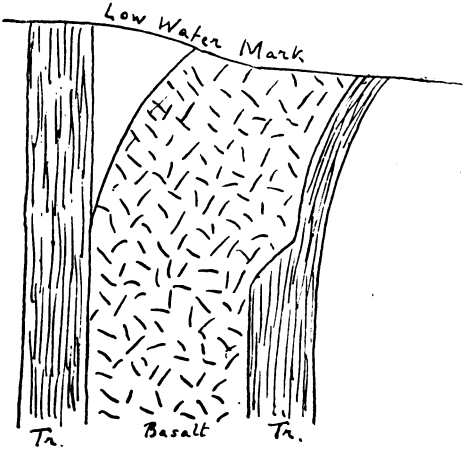

Fig. 4.—Plan of Trachyte and Basalt Dykes, Clashfarland Point, Great Cumbrae.

line. At Lady Bay a dyke of Markle basalt, 37 feet thick, forms a conspicuous feature on the raised beach. It has a wall-like outcrop divided into rhombohedral masses by jointing. South of Holm Bay Markle basalt dykes are thickly developed.

At Clashfarland Point a Dunsapie basalt and two bostonite dykes are associated in such a way as to suggest that the bostonite is the later intrusion (Fig. 4). It is clear from the figure that the bostonites have been guided by the previously intruded basalt.

At Davy's Rock, about 1 mile N.E. of Keppel Pier, the crag at the back of the raised beach shows a group of three

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E.N.E. dykes, one Dunsapie and two Markle, the Dunsapie being in the centre. A strip of intensely baked vitreous-looking quartzite intervenes between the northern Markle and the central Dunsapie basalt.

(*d*) Dykes, sills, and plugs of bostonite, keratophyre, and felsite.

As remarked before, some of the bostonite intrusions are earlier than the E.N.E. porphyritic basalts, but the majority are probably of a somewhat later date, especially the bostonite dykes, as shown by the two examples detailed in the last section. Both dykes and sills strike in an E.N.E. direction, parallel to the E.N.E. basalts. The following are the detailed observations made on a few of the bostonite intrusions. One-third of a mile north-east of Nupkur Point (west of Millport Bay) there is a thick dyke of trachytic appearance, grey in colour, and weathering into platy masses. It hades at a slight angle to the east of south. It is probably a bostonite, but it proved too decomposed for exact determination. The albite-bostonites of Craignan Fitheach have been referred to in the foregoing section. A thick dyke of columnar, red, porphyritic bostonite runs in an E.N.E. direction along the path west of Upper Kirkton.

From this point to the north end of the island no bostonites have been encountered on the west coast of the island. At Tomont End, the extreme northern point, there are two or three thin dykes of albite-bostonite; and 200 yards east of the Monument there is a very massive E.N.E. dyke, probably 100 feet thick, of quartz-keratophyre. About $\frac{1}{4}$ mile north of Downcraig Ferry there is an interesting group of five felsite dykes on the foreshore (Fig. 5). The southernmost of these is a thin, decomposed, platy, non-porphyritic rock, which is immediately followed by a mass of porphyritic felsile. This appears to be intermediate between a dyke and a boss. Its northern edge is straight, vertical, and altogether dyke-like, but the southern edge is very sinuous, although it appears to have a vertical contact with the adjacent sandstone. After a short interval of sandstone occurs a thin dyke of red felsite with a well-marked flow structure. The flow structure, however, is

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most beautifully developed in the two northernmost dykes, which are banded in contrasted streaks of yellow and dull purplish tints. Within each band flow is indicated by more subtle graduations of tint, and also by vesicles so drawn out as to appear mere cracks. Mr. John Smith has described the flow structure in one of these dykes (1902, p. 62). The thickness of the dykes is not determinable, as they lie between tide-marks and are more or less covered by seaweed and sand.

The Keppel peninsula, east of Millport Bay, shows numerous dykes and sills of bostonite which traverse the hill between

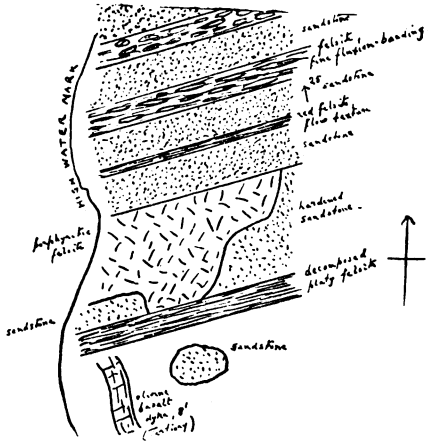

Fig. 5.—Plan of Felsite Dykes on shore, ¼ mile north of Downcraig Ferry, Great Cumbrae.

Millport Bay and the south-east coast of the island. One dyke, at least 50 feet thick, occurs at the back of the raised beach in the crag called Green Goat, about 1 mile N.N.E. of Keppel Pier. It can be traced in a W.S.W. direction to the Ninian Braes. A second thick dyke starts from a point 300 yards north of the Lion Rock, and can be traced across the peninsula into Millport Bay, where it is 22 feet thick. A third emerges on the coast just at the point where the N.W. Tertiary dyke of the Lion Rock appears, and is seen to be cut by it in a fine section on the shore. The albite-bostonite dyke is here 21 feet thick, and contains hard nodules of a porphyritic

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albite-keratophyre. To the W.S.W. it passes up into the old sea cliff, and here gradually assumes the characters of a sill. In the Red Craigs, near the Marine Biological Station, it is a true sill, interstratified with the Upper Old Red Sandstone, but its continuation is lost at the western end of the cliff. All these dykes are traversed by the two principal Tertiary N.W. dykes.

Six thick bostonite dykes may be seen on the eastern shore of Millport Bay, two of which, as above stated, may be traced across the peninsula to near Keppel Pier. Near the extremity of Farland Point occur two little elongated masses of albite-bostonite. Both masses are not more than 50 yards long by 10 yards wide. The northern one is elongated in an E.W. direction. At its west end the contact plane may be seen dipping at 30 degs., and resting on sandstone. In spite of this the outcrop indicates a boss-like mass or a short, thick dyke, as sandstone can be traced all around it. The southern mass reaches low-water mark on the east, and terminates here, as sandstone entirely surrounds it. From this mass an E.N.E. bostonite dyke appears to spring, and continues across Farland Bight.

At Barbay Hill, nearly in the centre of the island, there is an extensive outcrop of a bostonite sill. It has a very irregular boundary, but is extended in a general E.N.E. direction. Excellent fresh material may be obtained in a small quarry east of a pond called Wee Minnemoer, where an E.N.E. dyke of Jedburgh basalt has penetrated the bostonite and somewhat hardened it.

(*e*) Jedburgh basalts.

The evidence for the relative age of this small group is slender. One of the dykes cuts the Barbay bostonite, and is therefore later than it. But the age relation of the whole group is doubtful; it is doubtful even whether it constitutes a natural age group. Some of the dykes may be contemporaneous with the E.N.E. porphyritic basalts. Since the group has petrographic individuality, and the dykes as a whole appear to trend more to the N.E. than to the E.N.E., it is better to treat them separately.

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North of Sheriff's Port a Jedburgh dyke, 35 feet thick, is seen. At Skate Point a N.E. Jedburgh dyke, 12-14 feet wide, traverses the sandstone close to the small boss of Jedburgh basalt at this point, and encloses xenoliths of the adjacent rocks. A Jedburgh dyke, 16 feet thick, crosses the north end of the island from White Bay to the Monument, and forms the face of the cliff called Tomont End, at the back of the raised beach. This dyke becomes decomposed and vesicular at its margins, but also has parallel bands of vesicular material towards the interior. At Holm Bay, on the eastern coast, a Jedburgh dyke, 21 feet thick, appears. Alongside the road south-west of Downcraig a coarse ophitic Jedburgh dyke is exposed.

The thin Jedburgh dyke cutting the Barbay bostonite has already been mentioned. A ¼ mile south of Barbay Hill is another Jedburgh dyke; and two more are seen traversing Gourd Hill, near the hospital, in a N.E. direction. One of these is seen in a quarry, in which 20 feet thickness of the dyke occurs without exposing its margins.

2. Permo-Carboniferous (?)—E.W. dykes of quartz-dolerite.

These dykes are distinguished by their great breadth and by their length, as well as by their distinctive petrographical characters. Two of them occur in the Great Cumbrae, and Mr. Gunn has described them so fully that little can be added to his report (1903, p. 62). One appears on the coast at Sheriff's Port, and can be traced eastward to near Ballykellet, in the neighbourhood of the great N.S. fault. In its course it traverses E.N.E. dykes and a bostonite intrusion near Play Hill. Its average width is about 50 feet.

The second dyke appears on the western shore at the northern end of Fintray Bay, where it is about 100 feet thick. Here it is much decomposed, and shows the usual spheroidal masses and orange-coloured weathering, by which it is easily traced to near Figgatoch. At Fintray Bay its margin approaches an E.N.E. dyke, which it ultimately runs alongside, its course having been distinctly deflected by the presence of the earlier dyke. At Figgatoch there is a break in the continuity of the dyke, but it resumes its course at a more northerly point, and is seen

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near the roadside and in quarries on Tonnel Hill. East of Tonnel Hill, in the neighbourhood of the great N.S. fault, it is again shifted to the north. It reappears on Horse Hill, and passes out to sea at Downcraig Ferry, where it is 75 feet wide. Mr. Gunn has remarked the similarity of this dyke, in respect to its continual shifting, to those near Dunoon and Rothesay. The Downcraig dyke is apparently continued on the Ayrshire mainland, exactly opposite, by an E.W. dyke in the southern part of the town of Largs.

3. The Tertiary suite.

These dykes trend in a direction between N.W.-S.E. and due N.S. They belong to at least three different petrographic types, of which a new type (cumbraite) of "andesitic basalt" is the most important (Tyrrell, 1917 (2), pp. 306-13). These dykes have a very characteristic macroscopic appearance, and are easily identified in the field (see Petrography, *postea*, p. 268). The larger dykes average about 20 feet in width, and may be traced for distances upwards of a mile. The dykes of the Cumbrae type trend, as a rule, to the N.N.W., but those of another type, crinanite or olivine-dolerite, tend to take a N.S., or even N.N.E., direction. They are all part of a great suite of Tertiary N.W. dykes which are widely spread over the Clyde area (Tyrrell, 1917 (2), p. 354).

Starting at the south-western corner of the island, a N.N.W. dyke (allied to cumbraite), 3 feet wide, occurs near Nupkur Point. At Portachur Point there is a good section showing a N.W. dyke (tholeiite, Brunton type) cut by a dyke of similar type, which, at the junction, runs in a N.N.E. direction. Traced to the north, however, it splits into two branches, one of which continues in a N.N.E. direction, and the other follows a rather irregular N.N.W. course for $\frac{3}{4}$ mile, intersecting a number of the Carboniferous E.N.E. dykes.

The Clate Rock, $\frac{1}{2}$ mile south of Fintray Bay, is a N.N.W. dyke for most of its course, but on the shore turns due north, and intersects some of the Carboniferous E.N.E. dykes. It consists of an ophitic olivine-dolerite, and is 21 feet wide. In Little Skate Bay a N.N.W. dyke, only 8 inches wide and perfectly straight, may be seen cutting the Carboniferous E.N.E.

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dykes in this locality. Between Skate Point and Eerie Port at least three N.N.W. dykes are exposed on the shore.

A large N.N.W. dyke at Eerie Port, on the north-west coast of the Great Cumbrae, provides the type example of the newly described rock known as cumbraite. It is 29 feet wide, and has a slight hade to the W.S.W. The centre of the dyke, in the little crag by the roadside, is more glassy looking than the rest of the dyke, but this patch is quite local, and has no extension along the length of the dyke. Petrographic examination shows that this patch is not actually richer in glass than the surrounding rock, but that the glass is somewhat fresher, giving rise to a more vitreous lustre. This dyke may be traced through Grey Craigs towards the centre of the island, but it disappears $\frac{1}{4}$ mile north of Tonnel Hill, where sandstone is seen right across its course.

On the raised beach, about 200 yards N.E. of Grey Craigs, is a N.S. dyke of crinanite, which is 30 feet thick. It appears to terminate on the raised beach, as it cannot be found on the shore. Another dyke of the same type runs in a N.N.E. direction north-east of Figgatoch, but can only be traced a short distance.

Very few Tertiary dykes are seen near the north end of the island. A N.N.W. dyke, 3 feet wide, occurs in Holm Bay, and north of Downcraig Ferry there is a N.S. dyke of crinanite 8 feet wide (see Fig. 5).

Two fine Tertiary dykes occur in the south-eastern part of the island, both forming remarkable features on the raised beach. One forms the so-called Lion Rock, about $\frac{1}{3}$ of a mile north-east of Keppel Pier. This dyke makes a wall on the raised beach about 15 feet high, and is broken in such a manner as to suggest at a distance the profile of a couchant lion. On the shore the dyke is 16 feet wide, and breaks through an E.N.E. bostonite dyke (see p. 255). It may be traced inland to the Ferry road, a distance of 1 mile, where it ends abruptly against the main N.S. fault. It is exposed in a quarry by the roadside east of Ballykellet.

The second dyke (the "De'il's dyke") occurs at the Marine Biological Station, near Keppel Pier, where it forms a wall on the raised beach, reaching a height of 30 feet. It averages

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20 feet in width, and on the shore splits into two sections, which reunite at low-water mark. Inland it pursues a rather sinuous course, and becomes very irregular where it breaks through the three broad bostonite dykes which cross the south-eastern peninsula. East of Kames Bay it turns to the north, then to the N.N.E., and finally resumes a northerly direction, which, if continued, would cause it to join the Lion Rock dyke, but no junction can be traced. Both these dykes are cumbraites.

Petrography.

1. The Calciferous Sandstone suite.

(*a*) Porphyritic basalts.

These belong to the Markle and Dunsapie types (Tyrrell, 1912, pp. 229-230), of which the first named is the most abundant. Both types occur with equal frequency in dykes, sills, or plugs, but only Markle basalts amongst the lavas of the Little Cumbrae. Of the *Markle* basalts many examples are quite typical, showing numerous conspicuous porphyritic felspars in the hand specimens. The rocks are usually quite light in colour, especially when somewhat altered, but in the fresher types the groundmass is dark grey or black, and the porphyritic felspar clear and glassy-looking.

In thin section they show phenocrysts of felspar ranging in composition from acid labradorite (Ab_1 An_1) to labradorite-bytownite (Ab_3 An_7). These are frequently zonal, and give almost straight extinction in a thin marginal zone, indicating a transition to oligoclase. The average width of these felspars is about 4 mm., but occasionally phenocrysts twice this size are found. In the less fresh rocks albitisation of the large felspars is very common, the more basic cores being most frequently attacked. The groundmass is highly felspathic, and is composed of numerous microporphyritic felspars (Ab_1 An_1), with sparse pseudomorphs of serpentine after olivine, embedded in a microlitic base consisting of felspar, augite, and magnetite. The foregoing is a particular description of the third lava flow of the Little Cumbrae, but it will cover the majority of the Markle types of the Cumbraes, dykes, plugs, or lavas. The first, third, fourth, and fifth flows in the Little Cumbrae may

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be referred to this type. The first is a typical Markle; but in the others the phenocrysts, while numerous, are quite small, and the rocks are consequently transitional toward the Jedburgh type. In the third and fourth flows red, pleochroic flakes of iddingsite derived from the alteration of olivine are common in the groundmass. Furthermore, the felspar phenocrysts of the fourth flow contain numerous orientated inclusions of the groundmass crystals. Exactly similar rocks have been described from the contemporaneous lavas of South Bute (Smellie, 1916, p. 355).

On the Great Cumbrae typical Markle basalts are found associated with bostonite in the composite plugs of Sheughends and Play Hill (see p. 249). These differ in no essential features from those described above. In the Play Hill basalt the large labradorite phenocrysts are in some cases bordered by orthoclase, against which their multiple twinning stops short. The intrusive rocks are generally found to be more altered than the Little Cumbrae lavas, and the felspars, in many cases, are carbonated rather than albitised. Here, again, however, the alteration is confined to the more basic cores, whilst the more acid marginal parts remain quite fresh. With these rocks may be associated the rock of the Manse plug, and many of the porphyritic E.N.E. dykes, notably those at Davy's Rock (one of these carries large crystals of apatite); at the Boathouse, ¼ mile south of Holm Bay; and Lady Bay, on the east coast; and Doughend Hole, on the west coast. A dyke north of the Clate Rock may be cited as a case of the intimate association of a typical Markle and a typical Jedburgh basalt in one and the same intrusion (see p. 253).

Dunsapie basalts are quite common amongst the plugs and dykes, but do not occur within the lavas. They are, however, less frequent than the Markle types. The majority of them belong to a variety very common in the Clyde plateau, in which the felspar phenocrysts are far more numerous than those of augite and olivine, thus showing a transition toward the Markle type. A good example is the E.N.E. dyke cutting the Bell Craig vent. This shows numerous large porphyritic felspars, with much less numerous but large phenocrysts of olivine and augite. It is estimated that the felspar phenocrysts are about

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twice as numerous as those of augite and olivine put together. The groundmass shows the usual microlitic felt of felspar, augite, and iron ores, with the addition of patches of brown serpentinous material and numerous irregularly shaped microphenocrysts of an iron ore. The ferro-magnesian constituents of the groundmass have a slight predominance over the felspathic. The phenocrystic felspars are in all respects similar to those of the Markle types. The augite is euhedral, and encloses numerous crystals of magnetite. It is of a pale purplish colour, especially in basal sections, and is faintly pleochroic. In prismatic sections the colour tends to be a pale grey-green, with a tinge of purple. The olivine is completely pseudomorphed by brown and green serpentine.

Dykes of this type occur south of Keppel Pier, at Clashfarland Point (distinguished by large patches of secondary analcite), Craignan Fitheach (containing vesicles filled with glassy material and subvariolitic felspars), north of Doughend Hole (an almost microporphyritic type with fresh olivine), and near the 300 feet contour south of Barbay Hill. The rock of the little boss $\frac{1}{4}$ mile N.W. of the Lion Rock must also be referred to this group. The felspar phenocrysts are large, feebly zoned, and enclose numerous irregular patches of the groundmass. They belong mainly to acid labradorite (Ab_1 An_1), and are far more numerous and larger than the olivine and augite, which attain only microphenocrystic dimensions. The augite is frequently much altered, and the olivine is always completely carbonated. A few ilmenite phenocrysts attain a large size, and enclose felspars. The groundmass in this rock is very dense, and carries small microphenocrysts of labradorite, less numerous carbonate pseudomorphs after olivine, and flakes of red biotite, in a base consisting of closely packed microlites of iron ore and an ill-defined, feebly birefringent felspathic substance. This rock is quite close to the Markle type of basalt.

A much more basic type of Dunsapie basalt occurs as the plug almost entirely filling the Bell Craig vent. This is a dense black rock, remarkable for large and numerous augite phenocrysts, which reach in some cases a length of 3 inches. Smaller and less abundant phenocrysts of felspar and olivine

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may also be detected in the hand specimen. In thin section all the minerals are seen to be remarkably fresh. The phenocrysts are augite, olivine, labradorite (Ab_2 An_3), and ilmenite. The plagioclase is quite subordinate in quantity to the mafic constituents. Both plagioclase and augite (the usual purplish variety) have been rounded or corroded into irregular shapes by the action of resorptive processes, and both contain large inclusions of groundmass material. The olivine is euhedral, and has suffered only incipient serpentinisation along fissures. The groundmass is dense, and consists of microporphyritic felspars embedded in a close felt of magnetite, augite, and felspar microlites. This rock has a great general resemblance to the rock which contains the large augite crystals in the Black Rock vent on the shore south of Fairlie (Young, 1893, pp. 13-15).

The only other rock approaching this type is a dyke which forms the central member of a group of three contiguous dykes at Davy's Rock, the other two dykes being Markle basalts. This rock, however, is somewhat richer in porphyritic felspars than that of Bell Craig. The latter, perhaps, should be regarded as a Dunsapie basalt transitional to the Craiglockhart type, as it is very rich in olivine and augite.

(*b*) Non-porphyritic and microporphyritic basalts.

Twelve examples of basalts referable to the *Jedburgh* type have been noticed, all of which are intrusive rocks, and occur in the Great Cumbrae. A typical microlitic Jedburgh basalt forms the rock of the small plug at Skate Point. This is a hard, fresh, grey rock, showing in thin section numerous microporphyritic crystals of basic andesine (Ab_6 An_5) and of olivine, the former slightly predominating in size and number. The felspars vary in a thin marginal zone to oligoclase, and the olivine is altered to green serpentine and carbonates. The groundmass is dense but holocrystalline. Its base is an ill-defined felspathic substance, in which are embedded microlites of colourless augite and magnetite.

A similar but much altered rock occurs in the little boss at Nupkur Point; and a dyke rock resembling this type, but with much fewer microporphyritic crystals, is found in the composite Markle-Jedburgh dyke north of the Clate Rock (see p. 253).

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The dykes belonging to the Jedburgh type are in general much altered. They do not show the abundant microporphyritic crystals of the Skate Point rock, and the groundmass is much coarser, consisting of lathy felspars fluidally arranged, with interstitial granular augite and magnetite. These dykes are found on the south side of Holm Bay; in White Bay; cutting the Barbay bostonite at Wee Minnemoer (this rock contains rounded patches of fine-textured material); near the Millport Hospital (vesicles filled with glassy material and felspar microlites); and at Gourd Hill (containing a few large phenocrysts of carbonated olivine).

An unusual type of Jedburgh basalt occurs in an E.N.E. dyke at Skate Point. It shows rather large microporphyritic felspars (Ab_1 An_1) and a little serpentinised olivine in a groundmass consisting of long, slender felspars in ophitic relations with numerous small, deep-purple plates of augite and small grains of ilmenite. So far it resembles several of the Jedburgh types from the Kilpatrick Hills and elsewhere (Tyrrell, 1912, p. 232). The unusual feature is that it contains analcite and fibrous zeolites in the groundmass, and also in several rounded areas which are bordered by tangentially arranged felspars. In these areas the analcite is fresh, and clearly of primary origin. Analcite and other zeolites are, of course, well known as secondary minerals within the Calciferous Sandstone lavas, but they have rarely been recorded as primary constituents of the rocks. The Skate Point dyke differs from the crinanites in its poverty in olivine, in fineness of grain and in its micro-ophitic, combined with fluidal, texture.

Coarse-textured ophitic rocks of the usual Jedburgh habit are found in dykes N.E. of Clashfarland Point, on the roadside $\frac{1}{4}$ mile S.S.W. of Downcraig Ferry, and north of Sheriff's Port.

Mugearites are well represented in the lavas of the Little Cumbrae, but are not known amongst the intrusive rocks of the Great Cumbrae. The sixth flow is a typical mugearite. It consists of minute oligoclase laths and magnetite, with augite represented by interstitial alteration products. Each felspar lath appears to be bordered by a thin zone of alkali-felspar. A high-power objective reveals an abundance of apatite needles. The seventh flow is a very similar rock, which contains a few

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microporphyritic felspars and fresh augite. The second flow is a felspar-magnetite rock texturally identical with the sixth flow, but its felspars are more basic, belonging to andesine (Ab_5 An_3). It is classed therefore as a *basaltic mugearite.* The eighth flow has a similar groundmass, but carries numerous small phenocrysts of acid labradorite (Ab_1 An_1). It is therefore mugearite transitional to Markle basalt.

(*c*) Bostonites, keratophyres, and felsites.

These rocks have recently been described in a paper which dealt generally with the bostonitic and trachytic rocks of the Clyde Carboniferous lava plateaus (Tyrrell, 1917 (1), pp. 288-299). The terms bostonite, trachyte, and keratophyre are used with textural significations for rocks which have essentially the same chemical and mineral composition. The bostonites are comparatively coarse-grained rocks, with equidimensional crystals which have a more or less perfect fluxional arrangement. The trachytes are of much finer grain, and their groundmass is composed of minute felspar laths with a good fluxional or trachytic texture. Trachytes in this sense have not been found in the Cumbraes. The keratophyres have a dense felsitic groundmass, in which the constituents are devoid of fluxional arrangement. All these rocks are characterised by the predominance of alkali-felspars (albite and orthoclase). The sparse ferro-magnesian minerals have generally gone over into chlorite and limonite, which represent original pyroxene and biotite. Fresh biotite is seen only rarely, pyroxene hardly at all.

In the Great Cumbrae the majority of the rocks of this group are rich in albite, and may consequently be designated as albite-bostonite or albite-keratophyre. Other types, however, of which the Barbay sill is the representative, have approximately as much orthoclase as albite, and are therefore bostonites or keratophyres, according to their textures.

The felsites are more quartzose than the foregoing, and generally have a dense cryptocrystalline matrix. They are represented by several dykes on the north-east coast of the Great Cumbrae.

Bostonite.—The rock of the Barbay sill may be taken as

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representative of this group. In thin section it shows numerous phenocrysts of sanidine, generally elongate and simply twinned, in a groundmass consisting of slender laths of orthoclase with a little interstitial quartz and magnetite. A multiply-twinned felspar, near albite in composition, forms a subordinate part of the groundmass, but it is probable that the potash felspar, both phenocrysts and groundmass, contains some admixture of the albite molecule. The texture of the rock is fluidal, but the orientation of the felspars of the groundmass is not constant over all the field. Mr. J. V. Harrison found in this rock Na_2O, 4·42%, and K_2O, 4·33% (Tyrrell, 1917 (1), p. 297). Rocks similar to this, but containing a little biotite, are to be found in Kames Bay. In one of these Dr. Teall found 11% of alkalies, in which potash was predominant. A rock with remarkably slender felspars in the groundmass and a fine fluidal texture occurs in the E.N.E. dyke cut by the Lion Rock dyke. This rock also carries a little fresh biotite. Other bostonites occur in the little bosses at Farland Point, and in dykes at Clashfarland Point. Rocks characterised by a larger proportion of quartz than usual, and therefore designated as quartz-bostonites occur as dykes in Kames Bay and Lady Bay.

The *albite-bostonites* form perhaps a more numerous group than the bostonites, but are connected with these by intermediate graduations. They differ only in the greater abundance of a soda-lime felspar near albite. These rocks are found associated with Markle basalts in the composite intrusions of Sheugends and Play Hill (see p. 249), and also in the plug N.W. of Play Hill. The great dykes at Craignan Fitheach belong here, as also other examples at White Bay, and the crag called Green Goat on the east coast. The dyke at Upper Kirkton, and part of the rocks of Sheughends and Play Hill, are distinguished by the comparative abundance of quartz in the groundmass. Albite-bostonites occur as lavas in the Calciferous Sandstone eruptions of South Bute (Smellie, 1916, p. 359). The chemical and mineral composition of the group has been discussed in an earlier paper (Tyrrell, 1917 (1), p. 297).

A keratophyre in the sense adopted here occurs on the raised

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beach 200 yards north of the crag called The Butterlump, on the south-east coast. It shows a few sanidine phenocrysts in a groundmass of ill-defined, untwinned, unorientated felspar, with an abundance of iron ore, partly hæmatite, and partly ferruginous material breaking down into hæmatite, together with a little interstitial quartz. In a rock from Lady Bay the groundmass is much richer in quartz, and the abundant phenocrysts of felspar have been largely silicified. This may be regarded as a *quartz-keratophyre*. *Albite-keratophyre* is represented by the remarkable nodules found in the bostonite dyke cut by the Lion Rock $\frac{1}{4}$ mile north of Keppel Pier. This shows large phenocrysts of albite in a groundmass of short, stumpy crystals of untwinned, yellow-stained felspar, themselves embedded in an indeterminate, cryptocrystalline base.

The *felsites* are represented by the remarkable group of E.N.E. dykes north of Downcraig Ferry, one of which provides handsome material in hand specimens (see p. 254); also Smith, 1902, p. 62). The groundmass of these rocks is quartzo-felspathic, and may be minutely crystalline, although it is usually cryptocrystalline. Slender curved microlites apparently of some iron ore are present. Some of the dykes are non-porphyritic; others carry felspar phenocrysts which have been entirely replaced by cryptocrystalline silica without loss of crystalline form. Occasionally pseudomorphs in magnetite after biotite are seen, and the rocks are stained red or yellow with disseminated hæmatite or limonite. A similar felsite dyke also occurs on the shore just north of Lady Bay.

2. Permo-Carboniferous (?)—E.W. dykes of quartz-dolerite.

Two broad dykes running in a general E.W. direction are included in this section. They are entirely similar in petrographical character to the other E.W. dykes of the Clyde area (Tyrrell, 1909; Bailey, 1911, pp. 146, 148). They consist essentially of a plexus of labradorite laths in subophitic relations with a pale-coloured augite, with a large amount of skeletal ilmenite and a notable amount of primary interstitial quartz. Micropegmatite is not at all conspicuous in the Fintray Bay-Downcraig dyke, and alkali-felspar, distinguishable by its reddish alteration products, appears only at the Down-

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craig end of the dyke. The Sheriff's Port-Ballykellet dyke does not call for any special comment.

3. Tertiary dykes.

The Tertiary dykes includes at least three distinct petrographic types—cumbraite, tholeiite (Brunton type), and olivine-dolerite or crinanite, of which the first-named is the most important. A full description of cumbraite and a discussion of its affinities has been given in another paper (Tyrrell, 1917 (2), pp. 306-13), and it will only be necessary here to give a short synopsis of its characters.

Cumbraite.—These dykes have a very distinctive macroscopic appearance. They have a dense, black or dark grey, glossy base, with a vitreous lustre, in which large, scattered, white or yellow phenocrysts of fresh basic felspar are set. In the Eerie Port dyke, which is taken as typical of the series, an irregularly bounded central part shows a more vitreous lustre than the rest of the dyke, a feature which is also shown in a similar dyke from the Toward peninsula, Cowal (Clough, 1897, pp. 131-2, 136), and which is probably related to the "sheath-and-core" structure shown in many dykes, especially that of Eskdalemuir (Dumfriesshire) described by Sir A. Geikie (1880, p. 242). Under the microscope these rocks show phenocrysts of plagioclase near anorthite in a groundmass of laths of acid labradorite (Ab_1 An_1), enstatite, augite, and abundant dark glass. The phenocrysts have a composition between Ab_{15} An_{85} and Ab_{10} An_{90}, *i.e.*, anorthite near bytownite. They are extremely fresh, have a sharply bounded, narrow margin of labradorite, and may reach a diameter of 1 cm. They carry numerous globulitic inclusions and "negative crystals" of dark glass extended parallel to 010. These are zonally arranged or confined to the centres of the crystals.

The groundmass shows laths of labradorite and prisms of pyroxene, both rather elongated and tending to a subvariolitic arrangement, embedded in a dark glass. The crystalline constituents and the glass are approximately equal in bulk. The pyroxene includes both enstatite and augite, which are usually intergrown in characteristic fashion, with the enstatite occurring as the central member of three prisms in parallel position. Fre-

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quently, however, the enstatite appears without the flanking augites, especially in the Ballykellet dyke.

The apparently dark brown glass of the groundmass may be resolved under a high-power objective into a colourless or pale yellow glass darkened by numerous black opaque microlites. It also carries many curved felspar microlites and little strings of iron ore granules, which may represent original microlites of pyroxene. The apparently more glassy central part of the Eeerie Port dyke differs from the stonier part only in the greater freshness of its glass. The glassy material of the stony facies shows the beginnings of devitrification. Calculations based on the mode and chemical analysis of the rock show that the glass must contain all the potash, a large part of the soda, alumina, and excess silica, which is shown in the analysis.

An approximate determination of the mode of the "stony" part of the Eerie Port dyke gave anorthite (Ab_1 An_9), 7; labradorite (Ab_1 An_1), 31; pyroxenes, 20; and glass, 42%; sp. gr., 2·706. The "glassy" interior gave anorthite, 10; labradorite, 26; pyroxenes, 22; glass, 42%; sp. gr., 2·706. A chemical analysis of cumbraite is given in Table I., along with an analysis of the Eskdalemuir "pitchstone," which is a textural variety of the same type, and the average hypersthene-andesite.

TABLE I.

	1.	2.	3.
SiO_2,	60·46	58·67	59·86
TiO_2,	·68	n.d.	·66
Al_2O_3,	14·85	14·37	16·93
Fe_2O_3,	1·14	1·64	2·86
FeO,	5·82	6·94	3·56
MnO,	·10	tr.	·22
MgO,	1·46	4·66	3·25
CaO,	8·19	7·39	6·36
Na_2O,	3·27	3·01	3·35
K_2O,	2·20	1·42	1·62
H_2O above 105° C,	1·42	2·02	1·08
H_2O at 105° C,	·63		
P_2O_5	·05	—	·21
BaO,	—	—	·06
	100·27	100·11	100·02

Sp. Gr., 2·680

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1. Cumbraite, Tertiary N.W. dyke (interior glassy facies).

II.4.3.4. (tonalose), Eerie Port, Great Cumbrae, Firth of Clyde. Analysis by Chetai Yu, B.Sc.; alkalies, TiO_2, and P_2O_5, by A. Scott, M.A., D.Sc.

2. "Pitchstone" (Cumbraite, Eskdalemuir type), N.N.W. dyke with "sheath-and-core" structure, II'.4'.3.4. (tonalose), Eskdalemuir, Dumfriesshire. Quoted from Sir A. Geikie (1880), p. 253.

3. Average hypersthene-andesite, II.4.3'.4. (tonalose). Calculated from 71 analyses of rocks described as hypersthene-andesite, hypersthene-augite-andesite, bronzite- and enstatite-porphyrite, enstatite-diabase-porphyry, and bronzite-tholeiite; taken from Iddings, Igneous Rocks, vol. ii., 1913; Iddings and Morley, paper on Japanese Volcanic Rocks, *Proc. Nat. Acad. Sci., Washington*, vol. ii., 1916; Rosenbusch, Gesteinlehre, 3rd edition, 1910; Washington, Prof., Paper 14, U.S. Geological Survey, 1903, &c.

The chemical composition of cumbraite has been fully discussed in a former paper (Tyrrell, 1917 (2), pp. 312-4).

Tholeiite (*Brunton Type*).—This is a basaltic type founded on the so-called augite-andesite of the Brunton dyke of Northumberland, figured by Harker (1908, p. 203, Fig. 54), and first described and figured by Teall (1884, pp. 236, 237, Pl. XII., Fig. 6). It consists mainly of augite and labradorite developed in approximately equal quantity, with a subordinate amount of dark glass. There may be a negligible amount of olivine and magnetite, and in some Ayrshire varieties there are phenocrysts of anorthite, just as in cumbraite (Tyrrell, 1917 (2), pp. 350-2). The texture is typically intersertal or tholeiitic. Chemically the type is considerably more basic than cumbraite, as is shown by the chemical analyses of certain dykes from Mull (Geological Survey, 1914, p. 82; 1915, p. 55), and by the norms calculated from them, which show little or no excess silica and only about 5% of orthoclase. Only one good tholeiite of the Brunton type occurs in the Great Cumbrae, forming a N.W. dyke 11 feet thick, at Portachur Point. This consists of a plexus of almost colourless granular augite, with subordinate labradorite laths, and magnetite, embedded in a dark, partly devitrified glass which fills up the interspaces. There are a few small phenocrysts of bytownite (Ab_1 An_3). Although the texture is intersertal in the mass, there is also a tendency to sub-ophitic relations between the small augite grains and the felspar laths. A N.S. dyke, which cuts the foregoing, is rather decomposed, but

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is probably of the same type. It is distinguished by carrying numerous small agates in vesicles.

Ophitic Olivine-dolerites and Crinanite.—Crinanites are ophitic olivine-dolerites which carry a small amount of interstitial analcite or radial zeolites (Flett, 1911, p. 118). They are inseparably associated with, and may be shown to pass by a graduated series of specimens into, ophitic olivine-dolerites, which differ from them only in the absence of analcite or radial zeolites. The group is typically non-porphyritic, free from glass, with ophitic and comparatively coarse-grained textures, rich in olivine, and carrying a deeply-coloured brown-violet titaniferous variety of augite (Tyrrell, 1913, pp. 307-9; 1917 (2), pp. 353-4).

An excellent crinanite occurs in an 8-foot dyke on the shore 300 yards north of Downcraig Ferry. It shows a coarse ophitic mesh of labradorite laths and large plates of purplish augite, with abundant anhedral fresh olivine, and iron ore, probably ilmenite. The triangular interspaces between the felspars are filled either with fresh colourless analcite, or with yellowish radial zeolites. The rock is so fresh that it is difficult to regard the analcite as other than a primary constituent. An exactly similar rock occurs as a thick N.W. dyke on the raised beach N.E. of Grey Craigs.

Olivine-dolerites belonging to this group occur in the N.W. dyke of the Clate Rock, 21 feet thick, on the shore ¼ mile north of Sheriff's Port; and in a thick N.N.E. dyke occurring inland about ½ mile N.E. of Figgatoch. These differ from the crinanites above described only in the absence of analcite or radial zeolites and in their somewhat finer grain.

Conclusions.

By far the larger part of the igneous rocks of the Cumbraes belong to the widespread Clyde plateau of Lower Carboniferous age. This great mass of flat-lying, predominantly basaltic igneous rocks stretches from Stirling to Campbeltown in one direction, and from Fintry to Dalry in another, originally covering in all an area of between 2000 and 3000 square miles (Geikie, 1897, p. 368). The Lower Carboniferous igneous rocks of the Cumbraes, along with those of South Bute, provide

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samples of that part of the Clyde plateau which has sunk below the waters of the Firth of Clyde. They are to be correlated on the one hand with the great masses of Calciferous Sandstone igneous rocks covering large parts of North Ayrshire and Renfrewshire, and on the other with the remnants of the same period of igneous activity in Arran and near Campbeltown.

Comparing the Calciferous Sandstone igneous rocks of the Cumbraes with those of South Bute, it is seen that the lavas in both areas comprise a Markle-mugearite series (Smellie, 1916, pp. 343-5); but in South Bute there are in addition Jedburgh, Dunsapie, and Craiglockhart basalts, with at least three flows of bostonite. The Cumbraes, however, show much greater variation in the petrographic character of the intrusive masses; and the types, which in South Bute occur amongst the lavas, occur here as plugs, sills, and dykes.

In Arran the Calciferous Sandstone lavas of the Corrie district are mainly Craiglockhart basalts, but little is known concerning the igneous rocks of the same age in other districts of Arran. Practically nothing is as yet known about the Lower Carboniferous igneous rocks of the Campbeltown district.

Turning now to the district of North Ayrshire and Renfrewshire, petrographic investigation has as yet only touched the margin of this great mass of igneous material. It is known, however, that the area contains perhaps the largest development of acid and subacid igneous rocks within the Clyde plateau (Wilson, 1916, pp. 86-89; Tyrrell, 1917 (1), pp. 288-99). Markle and Jedburgh basalts, with mugearites, are common amongst the terraced lavas of the hill stretching from Gourock to Ardrossan. Many bostonites, trachytes, keratophyres, and felsites, both dykes and sills, intrude the western edge of the lava block and the subjacent sediments. The Knockside Hills, near Largs, provide analogies to the composite Markle-bostonite intrusions near Millport (Wilson, 1916, p. 88, figs. 2, 3); and the Black Rock vent on the shore south of Fairlie (Young, 1893, pp. 13-5) contains an intrusive mass with large augite crystals very similar to that of the Bell Craig vent of the Cumbraes.

The bostonites and related rocks of North Ayrshire and Renfrewshire are probably connected with the presence of the great

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tuff vent of Misty Law, just as similar rocks are connected with the Meikle Bin vent of the Campsie Fells (Bailey, 1911, p. 109, 143-5, Figs. 7, 9). It is a question whether the bostonites, &c., of the Great Cumbrae should be regarded as outlying members of the same suite; or whether it should be surmised that they are connected with a tuff vent of the Misty Law type now sunken beneath the Firth of Clyde. The presence of lava flows of bostonite in South Bute lends some support to the latter hypothesis.

The Tertiary igneous rocks of the Cumbraes have been dealt with in relation to the whole Tertiary suite of the Clyde area in a recent discussion of the subject (Tyrrell, 1917 (2), pp. 312-3), and it is not necessary therefore to deal with them any further in this paper.

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XIV.—Notes on the Intrusive Rocks of West Renfrewshire. By P. A. Leitch, A.M.Inst.C.E., and A. Scott, M.A., D.Sc.

[Read 8th March, 1917.]

[Issued separately, 30th December, 1917.]

Introduction.

Throughout western Renfrewshire the rocks exposed are practically all of Old Red Sandstone or Carboniferous age. Sediments of Calciferous Sandstone age outcrop along the shore from Port-Glasgow to Wemyss Bay, and also to the south-west of Loch Thom, where they are underlain by Old Red Sandstone. A syncline with an approximately east and west axis occurs south of Greenock, but further to the south-west, Old Red Sandstone sediments are exposed in the middle of an anticline, the axis of which trends north-north-east and south-south-west. The remainder of the county is composed of the lavas and tuffs of Calciferous Sandstone age, together with a number of isolated intrusions and the volcanic vents of the Misty Law district. As the last named should more properly be considered in connection with the vents of north Ayrshire (Wilson, 1916) we do not propose to treat them in detail here.

The intrusions may be divided into three groups.

I. Basaltic Rocks of Calciferous Sandstone Age.—These comprise the sills of Lunderston Bay and Gryfe Castle, and a number of dykes in the Gourock and Kilmacolm district. The field evidence indicates that these are later than the sediments, while their petrological character assigns them to the Calciferous Sandstone volcanic episode.

II. Felsitic Rocks of Calciferous Sandstone Age.—These include the sill at Craigmushet, a number of intrusions to the south-west of Loch Thom and a sill (?) near Kilmacolm. With the exception of the last, these are all intrusive into the sediments, but there is little doubt that they do not represent the earliest phase of Carboniferous activity. They are probably of the same age as the acid rocks of the Cumbraes (see pre-

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ceding paper), and hence almost the latest of the igneous rocks of Calciferous Sandstone age.

III. East-West Dykes of Permo-Carboniferous (?) Age.—The chief intrusion of this group is a large dyke near Kilmacolm.

Petrography.

I. Basaltic Rocks.—A sill of very fresh Markle basalt is well exposed at the northern end of Lunderston Bay, and in a quarry on the hillside. At the latter locality a large dome-shaped mass of much decomposed, greenish material is seen in the midst of the basalt. This seems to be of the nature of a fumerole, and has induced considerable alteration and decomposition of the basalt in the immediate neighbourhood. The material of the mass must have been highly charged with vapours, the release of which during cooling has caused the alteration of the basalt. The green material is much too decomposed to admit of being sectioned, and it is impossible to determine its exact nature, though the appearance suggests a kind of ash. Similar occurrences are fairly common in the Scottish Carboniferous rocks, several being visible in a small quarry two miles east of Neilston.

The basalt consists of large porphyritic labradorite crystals in a medium-grained mesostasis of felspar, granular augite, altered olivine, and magnetite. The phenocrysts show complicated twinning and well-developed zonal structure. The felspars of the groundmass are mainly plagioclase of the same composition as the phenocrysts—about Ab_{45} An_{55}—though a little orthoclase is also present. The pyroxene is a greenish non-pleochroic augite, while the olivine is represented by serpentinous pseudomorphs. The structure of the groundmass is granular.

Two intrusions of basalt occur on the knoll immediately to the north of Gryfe Castle, near Bridge of Weir. The chief evidence of their intrusive nature is the prominent escarpment which surrounds them, and the comparatively coarse-grained groundmass of the rocks. The rock of the north-eastern intrusion, which is near the farm of Yonderton, and which apparently is the one marked in the Geological Survey map, shows a base of felspar laths, augite and magnetite grains, containing numerous, somewhat fragmentary, felspar phenocrysts

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accompanied by smaller serpentinised olivines. The porphyritic felspars are labradorite of a composition varying from Ao_{40} An_{60} to Ab_{50} An_{50}, while the felspars of the groundmass, which have often an irregular fluxion arrangement, are slightly more acid. Twinning on the pericline law is somewhat common. The olivine is completely serpentinised, and varies in size from the porphyritic crystals down to small grains in the groundmass. The granular augite is of a pale brownish-green colour, and is partly enclosed by the felspar. The rock is allied to the Jedburgh type, but differs from the latter in the presence of the porphyritic felspars.

The intrusion which forms the knoll north of Gryfe Castle is composed of a rock which, though resembling the Markle type, differs considerably from the above. The phenocrysts are labradorite, often with numerous inclusions of ferromagnesian material, olivine which is larger and much more abundant than is usual in the Markle basalts of this district, and scarce augite. The olivine is largely replaced by hæmatite. The mesostasis is fairly coarse-grained, and consists of brownish titaniferous augite and magnetite, sub-ophitically enclosed in felspar laths which are mainly labradorite and rarely orthoclase. The proportions of ferromagnesian and felspathic minerals are approximately equal. The rock, while allied to the Jedburgh type, has also some affinities with the Markle basalts, and therefore may be termed a Jedburgh-Markle basalt.

A number of isolated dykes are found in various localities throughout the district, and of these the most remarkable is that which occurs at the Lyle Road, between Greenock and Gourock. The strike is approximately north and south, and it can be traced for a distance of about 400 yards. It is exposed immediately to the south of Fort Matilda station, where it is 6 feet in width. Ascending the cliff towards Craig's Top another exposure is found at the side of the Lyle Road. Here the width has diminished to about 6 to 8 inches, and a few feet higher up the last exposure shows a width of 2 inches. Hence we have a case of a regular decrease in thickness as we ascend, and it is probable that the last exposure is within a few feet of the termination upwards of the dyke. Similar phenomena are described by Geikie with regard to the Cleveland Dyke, but in the latter case the thinning out is not so gradual. The

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dyke is intrusive into the lavas, and at the Lyle Road exposure the country rock is a fine-grained, olivine-poor basalt with rather acid plagioclase indicating an affinity with the basaltic mugearites.

The dyke rock is a Markle basalt of unusual type. It consists of large phenocrysts of felspar and olivine in a fine-grained groundmass of felspar laths, augite microlites, and magnetite. The felspar phenocrysts are labradorite of intermediate composition and very unusual rhomboid habit. Prism faces are usually absent, and the form development is b(010), c(001), and x(101), while the crystals are generally tabular parallel to b(010). The crystals show a paralleled orientation due to fluxion, and the form (010) is generally vertical throughout the mass. Sections perpendicular to b(010) show albite twinning, while complex interpenetration twins are also common. Though the habit is similar, these crystals differ from those of the well-known mineral of the rhomb-porphyry of southern Norway in composition, as the Renfrewshire mineral is labradorite, while the Norwegian crystals are composed of soda potash-lime plagioclase approximating to potash oligoclase. Though the olivine crystals are entirely replaced by serpentine, the reticulate structure of which suggests antigorite, the outlines are perfectly definite, and there is no evidence of any magmatic resorption. The groundmass is a closely packed "felt" of pyroxene and felspar microlites with scarcer grains of magnetite. Though the rock is by no means typical of the Markle basalts, it must, on account of the presence of porphyritic felspar and olivine, be included in that group.

About two miles south-west of Kilmacolm, in the valley of the Blacketty Water, several rocks which may be intrusive are found. There is practically no field evidence regarding their nature, but their freshness, compared with the altered state of the surrounding material and the comparative coarseness of the groundmass, suggests that they are intrusive. One of the occurrences, which is probably a sill of considerable thickness, is found at the southern end of the upper reservoir in this valley. The rock is a basalt with numerous porphyritic felspars, with prominent zoning, set in a base of felspar laths, augite grains and abundant magnetite. The felspar phenocrysts are somewhat more acid than is usual in basalts of the

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Markle type, while the laths of the groundmass by their uniformly low extinction are probably andesine. Olivine is practically absent, and the abundant magnetite is segregated into bands and clots. A well-developed flow structure is seen in the groundmass. The rock might be described as a mugearitic Markle basalt.

A similar rock occurs a little further upstream, but in this case there is no segregation of the magnetite. The phenocrysts of zoned felspar are again very prominent, and occasionally show traces of albitisation. The whole rock is somewhat more basic than the one described above, but it must also be classed as a Markle basalt with mugearitic affinities.

II. Felsitic Rocks.—The most prominent acid intrusion is the sill at Craigmushet, Gourock (Montgomery (?), 1836). It is fully one-half mile long and about one-quarter mile broad, while the thickness must be at least 300 feet. It is exposed on the shore at the Coastguard station, and the western boundary can be traced round the foot of Barr Hill. The eastern boundary is not so well exposed, but it seems to us to continue somewhat further to the south-east than is indicated on the 1-inch Geological Survey map. The best exposures are in the large quarry south of the town.

Megascopically the quarry rock is greenish-grey, showing porphyritic felspars, green chloritic material, and quartz grains. Numerous specimens taken round the western margin are very similar, but at several exposures the rock is much stained by hæmatite. In the quarry a thick dyke-like mass of this red rock is also to be seen. Recent working has cut through this mass, which is conical in shape, and resembles an intrusion. As no sharp junctions are found, and as micro-examination shows no difference between the two rocks, save for the hæmatite staining, the obvious conclusion is that this red rock is merely the ordinary rock of the intrusion stained by iron oxide, and that this staining, which has taken place sporadically throughout the intrusion, is due to the percolation of iron-bearing solutions.

The quarry rock contains many large druses with a fair variety of minerals in them. These include well-developed quartz, calcite, barytes, and fluorspar (colourless, purple, and green). Miss Neilson has also observed tourmaline in small

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needles, while another reddish mineral occurring as minute grains gave reactions for antimony and manganese. Near the geodes the rock is permeated with chloritic material, and this has probably been introduced contemporaneously with the materials of the druses.

A section of this rock has recently been described by Mr. G. W. Tyrrell (1917, p. 294) and little can be added to his description. The porphyritic felspar is of two types, acid oligoclase, which is multiply twinned and sometimes albitised, and soda-orthoclase, which occasionally shows a very fine lamellar twinning. The groundmass is made up of euhedral felspar laths (probably soda-bearing orthoclase) in a matrix of felspar and quartz. The quartz, which is generally subordinate, is variable in amount, and some of it seems to be the product of juvenile reactions. Much chloritic material is disseminated through the rock, and also forms pseudomorphs after a ferromagnesian mineral. The original nature of the latter is difficult to determine, but a few unaltered residual portions suggest a pyroxene allied to diopside. Titanmagnetite and apatite are also present.

The iron-stained rocks have a very similar microscopic appearance, save for the presence of abundant hæmatite which has sometimes penetrated along the cleavage planes of the felspars. As a whole, the rock is a fairly typical quartz-keratophyre, and is comparatively uniform throughout the mass, the chief variations being in the amount of quartz and of porphyritic felspar.

Several intrusions of felsitic rock are found to the south-east of Loch Thom. One, which has a length of one-third of a mile, runs from the compensation reservoir in a south-westerly direction, and is exposed along the aqueduct which leads to Inverkip. Two others occur about one mile further south-west, and form small bluffs on the eastern side of the aqueduct, while another is seen 100 yards up a burn which passes under the aqueduct between these exposures. These rocks all resemble each other, and are not markedly different from the Craigmushet rock. Quartz is generally subordinate, and sometimes disappears altogether. The porphyritic crystals are oligoclase, accompanied by orthoclase which appears to be often a soda-rich variety. The groundmass is felspathic,

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and contains abundant iron-ore, which seems to replace a microlitic ferromagnesian mineral. The quartz-bearing rocks are typical quartz-keratophyres, while those which are quartz-poor or quartz-free may be termed keratophyre or bostonite according to the amount of orthoclase present. In some cases the groundmass has a subtrachytic structure which gives the rock a decidedly bostonitic aspect. As the difference between keratophyre and bostonite is mainly one of structure (see later), it seems advisable to class all of these rocks as keratophyres in view of the soda content. Several of the dyke rocks of the Misty Law District are very similar, though the amount of orthoclase is somewhat greater than in the rocks described above.

III. Permo-Carboniferous (?) Dykes.—The chief intrusion belonging to this group is the large dyke which is quarried at Rowantree Hill to the east of Kilmacolm. Although it can be traced in a direction slightly north of east for several miles, it is not marked on the 1-inch Geological Survey map. It is, however, mentioned in an unsigned manuscript of date 1836, which is in the Hunterian Museum. There is no indication as to the author, but Professor Gregory comparing it with the paper published by Wm. Montgomery in the *Transactions* of the Highland and Agricultural Society (1839) has arrived at the conclusion that it is by this author. The two papers have so much in common that there is little doubt regarding the correctness of this suggestion.

In the manuscript it is stated (p. 119) that "The dykes at Rashilee are each more than 100 feet thick and about 120 yards apart. How far they continue in this form is uncertain; they reach at least to the diluvial hill of South Barr . . . but beyond that only one dyke is known to exist," and on p. 116, "This" (the Rashilee) "dyke, it is said, may be first seen amongst the trap in the parish of Kilmacolm." A. Laird (1907, p. 248) refers to this dyke as belonging to the E.-W. type, and links it up with the more northerly of the two Rashilee dykes.

It may be traced from the Rowantree Hill Quarry across the Golf Course and through Corsliehills Wood to Haddockstone, while to the westward it may be followed across the Gryfe to East Green, two miles south-west of Kilmacolm. It is very probable

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that it is a continuation of one of the Rashilee dykes, though the ground is obscured for a considerable distance between the nearest exposures of the two dykes. The dyke is about 60 feet in width, and the rock considerable variation in texture, as it is very fine-grained at the margin, and shows a continuous gradation to a coarse-grained dolerite in the centre. Microscopically the rocks present the typical characters of the E.-W. quartz dolerite dykes (*cf.* Bailey, 1911, p. 146). The fine-grained margins consist of an aggregate of felspar laths (labradorite), colourless augite, and the typical skeletal ilmenite in a felspathic groundmass containing a fair amount of quartz. The central rock is more coarse grained, and the augite is very fresh, while the ilmenite tends to occur in large plates rather than in the skeletal forms. A little biotite is also present, while some chloritic decomposition products may represent olivine. Quartz occurs sporadically in the groundmass.

A curious rock, which is probably related in the E.-W. dykes, occurs apparently as a dyke in the valley of the Blacketty Water. It consists of unaltered labradorite laths and somewhat decomposed augite set in a groundmass of felspar, ilmenite, and quartz. Numerous pyroxenic belonites are scattered through the groundmass. The rock is much less altered than the quartz dolerites usually are, but its petrographical characters link it with the rock of the E.-W. dykes.

Petrology.

I. Basalts.—The petrology of this group of igneous rocks has been a subject of discussion since the appearance of Allport's paper in 1874. The most recent descriptions are those of Bailey (1911) and Tyrrell (1912), and the latter author in his paper on the Kilpatrick Hills gives a short history of the subject.

(a) *Markle Type.*—The intrusive basalts of west Renfrewshire mainly belongs to the Markle and Jedburgh types, and, although some have certain affinities with the Dunsapie and Dalmeny types, no definite examples of the latter have been found so far. The Lunderston Bay rock is remarkable for its fresh condition and the grain size of the groundmass. The porphyritic labradorite must have crystallised very slowly, and there is some evidence of considerable temperature variations during

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its formation. The crystals are usually zoned in an irregular fashion which suggests that there have been several periods of resorption and redeposition. The variation in size of the olivine indicates that the rock was "quenched" while the olivine was still crystallising. This sudden fall in temperature would inhibit the further precipitation of olivine, the residual ferromagnesian material crystallising as the granular pyroxene of the groundmass. In the case of the Blacketty Water rocks, the change from intratelluric to ordinary conditions must have occurred at an earlier stage, as the ferromagnesian material has crystallised mainly as augite. These rocks differ from the Markle basalts of the lavas in various ways. The latter, which are well exposed on the hills to the south of Greenock, and also westward of Kilmacolm, have generally fewer olivine phenocrysts, while the groundmass is much more fine-grained. The porphyritic felspars are also more albitised. Both the lavas and intrusive rocks of west Renfrewshire are somewhat coarser in grain than the corresponding rocks of the Glasgow district.

The rock of the Lyle Road dyke is an abnormal type of Markle basalt. The perfect form of the felspar and olivine phenocrysts indicates that their formation took place under a uniformly slow fall of temperature. Before the usual resorption of olivine took place, the quenching due to the act of intrusion took place, the augite and felspar of the groundmass crystallising during this period. The ferromagnesian constituents of the rock are thus probably metastable, for if the slow cooling had continued the olivine would have undergone resorption, and the resorbed material would have recrystallised as pyroxene. Though the rock differs from the usual Markle basalt in the unusual habit of the felspars and the uncorroded forms of the olivines, it may be classed as an "aberrant" type of the group.

(b) *Jedburgh Type.*—The rocks of this group show some affinities with the Markle and Dalmeny basalts. They tend to pass to the Markle type by an increase in the size of the labradorite phenocrysts, and to the Dalmeny type by an increase in the amount of olivine, and occasionally by the titaniferous nature of the pyroxene (*cf.* Tyrrell, 1912, pp. 236-8). The cooling history may be summarised thus. The por-

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phyritic crystallisation commenced under intratelluric conditions and the formation of "basic" plagioclase and olivine took place comparatively slowly. Before the temperature at which resorption of the latter became appreciable was reached rapid cooling supervened, so that the metastable olivine remained precipitated. During this comparatively rapid fall in temperature the augite and the felspar of the groundmass crystallised out. Even if the slow cooling had continued it is probable that the resorbed olivine would have been partly reprecipitated. The subophitic structure cannot, however, be regarded as an eutectic, even although there are only two types of crystals present. The crystallisation of two such complicated solid solutions as augite and plagioclase is in no sense analogous to the crystallisation of two simple substances, as not only is the composition of the liquid continuously changing, but the composition of each of the solid phases is also undergoing continuous changes, even when the equilibrium is only partial. Furthermore, even under the most rapid "quenching" there is no fixed minimum temperature at which a mixture of two solid solutions will consolidate. Bowen has shown that there is no eutectic between diopside and plagioclase, and there is no doubt that the same applies to the case where diopside is substituted by the more complex augite (*cf.* Bowen, 1915, p. 37).

The purple augite which is so characteristic of many of the Jedburgh basalts of the West of Scotland suggests affinities with a more alkaline type of basalt, and these rocks may possibly be the basic equivalent of the basaltic mugearites. The more basic Craiglockhart and Dunsapie types have not been found amongst the intrusive rocks of this district, but there are several occurrences of each in the eastern part of the county.

II. Keratophyres.—The acid rocks are typical members of the trachytic group of the Clyde plateau. Tyrrell (1917) has divided this group into three subdivisions, according to the felspar content, the first division including those rocks with dominant soda-felspar, the second comprising those with approximately equal quantities of potash and soda-felspars, while in the third are the quartz-bearing types. No very

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definite separation between bostonites, trachytes, and keratophyres is made. The Craigmushet rocks may be classed as keratophyres with variable amount of quartz, but some, owing to their subtrachytic structure, would, according to accepted usage, be classed as bostonites or quartz-bostonites. Indeed they resemble closely the rocks from Bute, so described by Smellie (1916, p. 353). The distinction between bostonite and keratophyre is slight, and not well defined. Keratophyres were first defined by Gümbel (1874, p. 43) as follows:—"Ein sehr vielgestatiges quartzführendes Orthoklas-Plagioklas-gestein mit anscheinend dichter hornfelsartiger aber noch mehr oder weniger deutlich feinkrystallinisch-körniger Grundmasse, und darin eingesprengten Feldspathennädelchen von vorherrschend regelmässigen rectangulärem Durchschnitt nebst Putzen (nie Krystallen) von Quartz, Körnchen von Magneteisen-vereinzellen Blättchen braunen Glimmers und Spuren von zersetzter Hornblende."

Lossen (1882, p. 199) emphasised the alkaline nature of the felspar. The Renfrewshire rocks agree exactly with the definition given by Rosenbusch (1910, p. 345). According to the last-named author the bostonites differ in being hypabyssal, and having often a trachytoid structure. The name bostonite was first applied by Hunter and Rosenbusch (1890, p. 446) to certain rocks from Marblehead Neck, Mass., which has been previously described by Wadsworth as trachyte, and by Sears (1890, p. 167) as keratophyre. It was adopted by Kemp and Marsters (1893, p. 18) for some similar dyke-rocks of the Lake Champlain region. Neither of Rosenbusch's distinctions seem of sufficient importance to justify the retention of the two names; hence all the acid rocks described above have been classed as keratophyres. The difference between intrusive and effusive basalts of the Markle type, for example, is often greater than that between the so-called bostonites and keratophyres, while petrologically the presence or absence of fluxion structure is of comparatively little importance. The term keratophyre should be applied to those rocks allied to the trachytes, but containing anorthoclase or albite as the dominant felspar. If it be desired to retain the name bostonite, then it might be applied to those rocks inter-

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mediate between the trachytes and keratophyres, and containing therefore approximately equal proportions of soda and potash in the felspar. This would still be in conformity with the type bostonite of Marblehead (Washington, 1899), which contains almost equal amounts of soda and potash (Table 1, No. 5). In the five analysis of bostonite given by Rosenbusch (1910, p. 271) the amounts of these two oxides are approximately equal, while in sixteen analyses of quartz keratophyre given by the same author (1910, p. 329) there is a large predominance of soda in all but two cases, the average quantities being Na_2O, 6·00 per cent., and K_2O, 1·28 per cent. Hence the term keratophyre might be reserved for those aphanitic subacid rocks with a dominant soda-bearing felspar, such as anorthoclase or albite, bostonite for similar rocks, in which the amounts of soda and potash felspar are more nearly comparable, and trachyte for the dominantly potassic type.

A sample taken from the quarry at Craigmushet was analysed, and the figures are given in Table I., column 1—

TABLE I.

	1	2	3	4	5
SiO_2	60·41	66·60	58·47	62·28	71·40
TiO_2	1·74	·55	2·17	—	—
Al_2O_3	16·06	12·95	18·60	19·17	14·76
Fe_2O_3	3·14	7·25	1·92	3·39	1·68
FeO	3·32	·83	4·77	—	·72
MnO	·28	—	·19	—	tr.
MgO	1·26	·76	·94	tr.	·55
CaO	2·07	1·41	·99	1·44	·10
Na_2O	4·87	6·14	5·52	5·37	4·79
K_2O	3·28	3·10	3·30	5·93	5·16
H_2O+	2·20	·46	2·19	2·33	1·46
H_2O-	1·66	·49	·50		
CO_2	·15	—	·04	—	—
P_2O_5	·23	—	·45	—	—
(BaSr)O	tr.	—	·04	—	—
F.	p.n.d.	—	·02	—	—
	100·67	100·54	100·11	99·71	100·62

1. Quartz-keratophyre [(I) II. 4 (5), 2, 4,] Craigmushet, Gourock.

2. Albite-bostonite [(I) II. 4, 1, 4,] Loch na Leighe, South Bute. W. R. Smellie (1916, p. 359).

3. Albite trachyte [(I) II. 4 (5), 1, 4,] Skomer Island, Pembrokeshire. H. H. Thomas (1911, p. 192).

4. Bostonite [I, 5. '2, 3',] Nash's Point, Vermont. Kemp and Marsters (1893, p. 20).

5. Bostonite [I. 4, 1, 3',] Marblehead Neck, Mass. H. S. Washington (1899, p. 293).

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Unfortunately it is impossible to obtain specimens free from the "juvenile" chloritic material, and the presence of the latter is reflected in the analysis. Practically all the magnesia part of the ferrous oxide, and possibly some of the potash represent the chlorite. The silica content seems to vary locally throughout the intrusion, as two specimens from the western margin contained 64·49 per cent. and 63·17 per cent. respectively. After allowing for the chloritic material, the rocks shows a close chemical resemblance to the so-called albite-bostonite from South Bute, which under the classification described above would be termed a keratophyre. The deficiency in potash in both the Craigmushet and South Bute rocks, compared with two typical bostonites from the United States, is indicated by a comparison with columns 4 and 5. The high alumina content, combined with the comparatively small amounts of the ferromagnesian oxides, is an indication of the felspathic nature of the rock. This is further borne out by a consideration of the norm (Table II., column 1)—

TABLE II.*

	1	2	3	4	5
Quartz	12·7	17·0	9·7	2·7	22·8
Orthoclase	19·5	18·4	19·4	35·0	30·6
Albite	41·4	49·2	46·6	45·6	40·3
Anorthite	9·7	—	2·2	7·2	·6
Corundum	·8	—	5·1	1·2	1·1
Acmnite	—	2·3	—	—	—
Diopside	—	4·1	—	—	—
Hypersthene	4·4	—	6·2	5·5	1·4
Wollastonite	—	·7	—	—	—
Magnetite	4·4	1·2	2·8	—	2·4
Ilmenite	3·2	1·0	4·1	—	—
Hæmatite	—	5·6	—	—	—
Apatite	·5	—	1·0	—	—
S/F Ratio	6·7	6·1	6·8		

* Norms 2 and 3 are taken from Tyrrell (1917, p. 298), and 4 and 5 from J. P. Iddings, Igneous Rocks, vol. ii., pp. 208, 386.

Like most of the rocks of this group in the Clyde plateau, the Gourock specimen lies on the borderland between Classes I. and II., while the relatively small amount of quartz places it in the fourth order. The preponderance of alkalic oxides over lime is not so striking, so that in this respect the rock resembles rather the Lennoxtown felsite (Tyrrell, 1917, p. 298).

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As far as the mode is concerned, it is probable that some of the lime is in the ferromagnesian mineral, which seems to be a pyroxene allied to diopside. Much of the iron oxides represented in the norm as magnetite are probably modally in the chloritic material, or in the abundant hæmatite which permeates the rock in many places. On the whole, the mode differs considerably from the norm, but the presence of secondary material and decomposition products, as well as the fine-grained groundmass, prevent the carrying out of any quantitative estimations.

The other acid rocks are microscopically very similar, the chief differences lying in the amount of modal quartz. So far as can be ascertained, the felspars are the same as those of the Craigmushet rock, and the whole group may therefore be classed keratophyres or quartz-keratophyres, accordingly as quartz is absent or not.

While these Renfrewshire rocks are to a great extent typical of the Calciferous Sandstone intrusives of the Clyde plateaux, the district is distinguished by the large development of acid types. The connection of the latter with the vents of the Misty Law District is undoubted, as this is the only area where these rocks show any tendency to preponderance. In the occurrences of the Campsie Hills, South Bute, and the Cumbraes the acid types are subordinate, though there is a decided increase in the two last localities, which are at no great distance from the region under consideration.

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No. XV.—Notes on the Microscopical Characters of the Blackbyre Limestone in the West of Scotland. By Peter Macnair, F.R.S.E., F.G.S.

[Read 12th April, 1917.]

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The megascopic features and stratigraphical position of the Blackbyre Limestone over a large part of central Scotland have now become so well established that there can scarcely be any dubiety regarding the correlations that have been made of this horizon in the east and west of Scotland (Macnair, 1917). In north Ayrshire it has long been quarried in the neighbourhood of Beith, Trearne, Hillhead of Broadstone, Dockra, Gatend, Oldmill, and Lugton, and also at Auchencloich, Kilbirnie, Howrat, Cunningham-Baidland, and Auchenskeoch, Dalry, and at Waterland and Gameshill, Dunlop. It can be followed from north Ayrshire through Renfrewshire into the Glasgow district, where it is exposed at the type locality near Blackbyre Farm, Barrhead, where it presents those distinctive characters seen over north Ayrshire. It is also magnificently displayed at Corrieburn, north of Kilsyth, at which locality it exhibits all the features seen both in the east and west of Scotland. In Fife it is characteristically developed on the shore between St. Monans and Pittenweem, and on the other side of the Forth in Haddingtonshire at Aberlady Bay, and on the coast south of Dunbar. What we believe to be the same stratigraphical horizon can also be traced far into the north of England.

At a variable distance below the Blackbyre Limestone and separated from it by terriginous sediments occurs the Hollybush Limestone, which presents many of the physical and palæontological features of the overlying Blackbyre Limestone, being essentially a brachiopod and coral limestone. They appear to have been deposited under similar physical conditions.

The Blackbyre Limestone presents all the essential features of a modern coral reef, and is generally seen to consist of massive bands of compound corals belonging to the genera

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Lithostrotion and *Lonsdaleia* occurring in masses, occupying the original position of growth, and strongly suggestive of reef formation. The top of the Blackbyre Limestone not infrequently exhibits a broken or brecciated condition indicative of contemporaneous erosion. This may be seen in some of the Ayrshire sections, but it is developed on a much larger scale on the shore between St. Monans and Pittenweem. Along with these reef-building corals there occur bands and masses of solitary corals belonging to the genera *Zaphrentis*, *Aulophyllum*, *Clisiophyllum*, *Dibunophyllum*, and others. Associated with these we find a large marine fauna consisting of brachiopods, gasteropods, polyzoa, &c., often in a more or less broken or fragmentary condition (Macnair, 1914, p. 38).

One of the most striking features of this limestone horizon is the frequent presence of a coal or fireclay, containing large branching stigmaria, immediately overlying it. In fact, the stigmaria appear to have been growing immediately upon the top of the brecciated or nodular surface of the limestone. In this respect it presents quite an unusual relationship between the coals and limestones of the Lower Carboniferous Limestone Series, for, as a rule, the coals are generally seen to underlie the limestone. From an examination of its physical and palæontological features it seems highly probable that the Blackbyre Limestone over central Scotland was not formed in deep water at a distance from the land as in the case of many detrital limestones; but it probably represents, as has been suggested, a fringing reef growing in clear, shallow water near land (Crampton, 1905, 1906).

Everywhere throughout north Ayrshire and Renfrewshire a bed of peculiar green, ashy, mud-like material is seen to rest upon the nodular surface of the Blackbyre Limestone. This bed was formerly considered to be of true volcanic origin, but the recently acquired evidence shows that it is more likely to represent a re-wash of ashy material from the old volcanic land surface. This band contains abundant ossicles of crinoids and fragments of fish bones, scales, plates, and teeth.

As a rule, the Carboniferous Limestones consist of the calcareous remains of foraminifera, sponges, echinoderms, brachiopods, bryozoa, and some problematical organisms more or less

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perfectly preserved and held together in a matrix or groundmass formed of shell *débris* or of re-crystallised calcite, while in some cases we have evidence of the presence of carbonate of lime which has been chemically precipitated; along with this usually occurs a certain amount of non-calcareous material derived from other sources. Thus in the Blackbyre Limestone we often find the spaces between the individual corallites of *Lithostrotion* filled in with a greenish clay which has been derived from the old volcanic land surface.

Contemporaneous and subsequent volcanic action, of which there is abundant record, and the different processes of metamorphism have locally destroyed the organic character of the deposits, but not so absolutely as to leave any doubt that we are dealing on the whole with the charnel heaps of a bygone marine fauna, by the study of which we can restore in some detail the oceanography of the period.

Dealing, in the first place, with the remains of the calcareous algæ which are found abundantly in the Blackbyre Limestone we may note the existence of *Girvanella* in the limestones of north Ayrshire at Trearne and Cunningham-Baidland. *Girvanella* was first found by Professor Nicholson in the Ordovician rocks of Girvan. In his paper in the *Geological Magazine* (1888, p. 15) he says, "*Girvanella* has so far only been recognised as occurring in the Ordovician limestones of Ayrshire. I have, however, found some of the Carboniferous Limestone of the north of England to contain an ill-preserved organism which will, I think, prove to be referable to *Girvanella*." This surmise turned out to be correct, as we find Mr. E. Wethered (1890, p. 270) describing two new forms of the genus from the Lower Carboniferous rocks of Avon Gorge and Totworth. From beds, partly oolitic, he had been able to determine two new species, which he named *G. incrustans*, with tubes having a diameter of 0·1 mm., and *G. Ducii*, with a diameter of ·02 mm. It is interesting to note that his specimens were obtained from the limestone where the bridge valley road joins the river bank apparently at the base of Dr. Vaughan's Upper Dibunophyllum zone. Professor Garwood (1913, p. 498) has traced a horizon, named by him the *Girvanella* Nodular Bed, throughout the whole of the north and

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north-west of England, and he considers that it occupies in that district the same stratigraphical position as it does in the Bristol area. Dr. John Young in his list of the Carboniferous Foraminifera of the Clyde drainage area refers to the occurrence of *Girvanella*, and, following Nicholson and Etheridge, he places it amongst the foraminifera, and records it from Muirkirk and Law Quarry, Dalry, both of which localities are in the Blackbyre Limestone. In an earlier paper (1890) on the internal structure of the Carboniferous corals forming the genus *Chætetes* Dr. Young refers to the existence of a minute twisted tubular organism which closely resembles

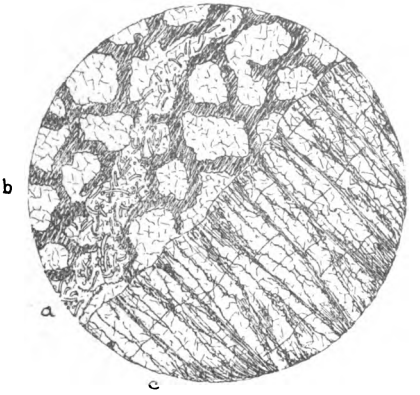

Fig. 1.—Thin section showing a, *Girvanella*, b, *Chætetes*, and c, *Tabulipora* growing together as a colony, from Blackbyre Limestone, Durnhunch, Muirkirk, Ayrshire, × 50.

Girvanella found by him in thin sections of masses of *Chætetes* from Durnhunch and Ashawburn, Muirkirk. In association with these is a third organism, *Tabulipora scotica*. An examination of these specimens now in Kelvingrove Museum confirms Dr. Young's determination, and shows that we have growing together in the same mass a calcareous alga, a coral, and a bryozoan, as shown in the figure in the text. Apart from these records I cannot find that Dr. Young has given any further description of the west of Scotland specimens. Professor Nicholson gives an interesting account of this minute organism from the Ordovician Limestone of Ayr-

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shire, to which he gave the name of *Girvanella problematica.* He says the organism bulks largely in the Craighead Limestones, and consists of nodular masses, varying in size from less than a mm. to over a cm., and appearing in long section-like bundles of smooth-walled, twisted tubules. In cross section the tubules are circular, each showing a central dot-like marking enclosed by two or three concentric rings, the diameter of the tubules varying in size from $\frac{1}{25}$ to $\frac{1}{60}$ mm. *Girvanella* was considered by Professor Nicholson, Mr. Etheridge, jun., and Mr. H. B. Brady to belong to the arenaceous foraminifera, and nearly related to such forms as *Hyperammina.*

In the year 1891 Rothpletz (1891. p. 301) pointed out that certain specimens of *Girvanella* which he had examined exhibited a characteristic dichotomous branching of the tubes, and because of this he removed the genus from the rhizopods to the calcareous algæ, placing it provisionally among the *Codiaceæ.* And about three years later Dr. A. Brown, when summing up the evidence in favour of the reference of the genus *Solenopora* to the *Nullipores*, says, "Should this view be finally established it will be an interesting proof of the extent to which the calcareous algæ have taken part in the formation of the older of the Palæozoic Limestones, as they are already known to have done in the case of some of the Tertiary and Secondary Limestones. This proof will be still further enforced if, as seems extremely probable, it should ultimately be shown that *Girvanella* (Nich. and Eth.) is really referable to the *Siphoneæ verticillatæ.* Rothpletz in 1908 gives it as his opinion that *Girvanella* must be regarded as an algæ, but places it in the *Codiaceæ* awaiting further investigation. Seward, in his "Fossil Plants," says some authors have suggested that *Girvanella* is a calcareous algæ which should be included in the family *Siphoneæ.* As a matter of fact, we must be content for the present to leave its precise nature as still *sub judice,* and while regarding it as probably an alga, we may venture to consider it more fittingly discussed under the *Schizophyta* than elsewhere. If we compare the specimens of *Girvanella* from the Blackbyre Limestone of north Ayrshire with that found in the Ordovician rocks of Craighead, Girvan, it will be found that the Carboniferous specimens seldom occur in nodules,

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though an occasional nodule has been found. The Ordovician specimens are twisted together in loosely reticulate or vermiculate aggregations of a rounded or irregular shape. But in those from the Blackbyre Limestone they mostly present a thinly incrusting-like arrangement, which in section has a linear or chain-like appearance. Isolated groups of tubules are found all over the thin sections embedded in the fragmental *débris* of foraminifera, sponges, bryozoa, and brachiopoda. These tubules have all the characters of the Ordovician species, but appear mostly to be of the maximum size described by Nicholson.

In one of the slides there occurs a remarkably well-preserved specimen, whose general structure bears a strong resemblance to *Girvanella*. It occupies an area of about 5 mm. square, and differs from *Girvanella* in the larger size of the tubules, and in the fact that instead of twisting about in all directions they are straight, and run parallel with the stem and deeper branching process. The general outline of the specimen is strongly suggestive of a very small recent *Melobesia*, in which a pair of branches curve in and become coalescent, thereafter ending in a single tip. Another *Melobesia* feature is the distinct line of growth which runs across the main body of the specimen at right angles to the tubules. We are of opinion since examining some typical *Ortonella* that this specimen is referable to that genus.

Another minute fossil organism now also referred to the calcareous alga *Mitcheldeania* was found by Dr. Young (1899, p. 228) in the Blackbyre Limestone of north Ayrshire, and a short account of it appears in the *Proceedings* of the Society for the year 1899. *Mitcheldearia nicholsoni* was first found by Mr. E. Wethered (1886, p. 529) in the Carboniferous Limestone in the Forest of Dean about the year 1886, and was referred by him to the *Hydractinidæ*, and considered to be allied to the *Stromatoporids*. Professor Nicholson (1888, p. 15) published a paper in which he gives figures and descriptions of a new species of the genus *M. gregaria*. This remarkable organism occurs in vast numbers in the Lower Carboniferous Limestone Series of parts of the south of Scotland and north-west Northumberland, and forms in places extensive beds of

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limestone. Professor Nicholson defines the genus as having the form of small rounded or oval calcareous masses made up of capillary tubes of an oval or circular shape which radiate from a central point or points, and are intermixed with an interstitial tissue of very much more minute branching tubuli. He compares the layers to zooidal tubes, and states that they communicate with one another by means of large, irregular-placed foramini, resembling the mural pores in the *Favositidæ*, and they occasionally exhibit a few irregular transverse partitions of tabulæ.

Professor Nicholson regarded the systematic position of *Mitcheldeania* as belonging to the *Cœlenterata*, its closest affinities being with the *Hydrocorallinæ*. On the other hand, he says all the known *Hydrocorallinæ* possess zoidal tubes, which are enormously larger than those of *Mitcheldeania*, and there are other morphological features in the latter genus which would preclude its being actually placed with our present knowledge in the group of the *Hydrocorallinæ*. Up till recently no further investigation of this problematical fossil has been made, and it seems generally to have been left where Nicholson placed it amongst the *Hydrozoa*.

Professor Garwood, in a paper published in the *Geological Magazine* for 1913, states that he has collected specimens both from the Forest of Dean and the English Border localities, and he says that a study of this material has greatly impressed him with the resemblance of *Mitcheldeania* to forms such as *Solenopora* and *Girvanella*, now classed among the calcareous alga. *Mitcheldeania* occurs in rounded and lobulate nodules, which break with a porcellaneous fracture, and show concentric structure on weathered surfaces.

Professor Nicholson seems to have mainly based his opinion that *Mitcheldeania* was allied to the *Hydrocorallinæ* on the presence of pores which he considered to exist both on the walls of the finer and larger tubules, though he seems to have been doubtful about their occurrence in the interstitial tubules. Professor Garwood says that he has examined a large number of slides, and that he has failed to observe evidence of the presence of pores even in the larger tubules. He explains the large oval or circular pores seen by Professor Nicholson as being due to the cutting across in section of the

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undulating tubes, and concludes that if this view be accepted there appears to be no sufficient reason why *Mitcheldeania* should not be ranged along with *Solenopora* amongst the calcareous alga, a conclusion which is still further borne out by its mode of occurrence and characteristic structure.

J. Stanley Gardiner has pointed out that an examination of modern coral reefs shows that they have been formed by corals bound together by other organisms. He further points out that corals form a definite class not existing below 25 fathoms in any luxuriance, and states that they feed mainly —and many entirely—by their commensal algæ, so that they, as also the millepores, are dependant for their growth on light and constant change of water.

Even a cursory examination of thin sections of the Blackbyre Limestone will be sufficient to show that the foraminifera do not play so great a part as rock builders as they do in the chalk formation, or in some modern deposits. Though rare, still there are a few rock-building forms, such as *Saccammina carteri*, which, however, does not make the same show upon the Blackbyre horizon as it does in the Hurlet of the Carluke district and in the Main Hosie or Skateraw Limestone of Dunbar. This genus is especially interesting amongst the Carboniferous foraminifera, inasmuch as it is the only one which occurs as a rock builder in this country. The tests are usually free, consisting of a single chamber of the average size of an eighth of an inch. It is spherical or pear shaped, and the labrynthic interior, usually filled up with clear crystalline calcite, is well displayed in thin sections. Though it is exceedingly difficult to determine the foraminifera in thin sections, yet the following genera have been made out:—*Saccammina*, *Climacammina*, *Trochammina*, *Valvulina*, *Endothyra*, *Stacheia*, *Textularia*, *Archædiscus*, *Globigerina*, and *Haplophragmium*. The following are some of the more common forms:—*Endothyra ammonoides*, whose test generally consists of four or five regular convolutions, and the chambers number between forty and fifty. *E. bowmanni* is also of frequent occurrence, and so is *Valvulina palæotrochus*, the latter easily recognised by its helmet-shaped tests. *Trochammina incerta* is also abundant, as well as *T. centrifuga*, *T. gordialis*, and *T. pusilla*. *T. gordialis* is very minute, and the tube

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is coiled irregularly in different directions, suggesting the gordian knot, from which appearance it has received its specific name.

The remains of sponge spicules are abundant in most of the thin sections of the Blackbyre Limestone, and are no doubt referable to the genera *Hyalostelia*, *Tholiasterella*, *Holasterella*, and *Pachastrella*. All these genera appear to have been furnished with siliceous spiculæ, a peculiarity of which is the immense size of the spicules compared with those of recent sponges. *Hyalonema smithii* is exceedingly abundant in sections from Cunningham-Baidland, where they occur as detached spicules of various forms. Many of these are simple hexactinellids, with six rays at right angles to each other. These spicules have a main axis, which varies in length from 1·5 to 9 mm. The two lateral axes are, as a rule, very unequal, the rays being occasionally inflated or reduced to a mere rounded knob. The spicules of this species have also been found at Trearne and Waterland, though they appear to be less common than at Cunningham-Baidland.

The corals scarcely fall under the category of microscopic objects, but it may be noted that they constitute a very large proportion of the organisms that go to the building up of the Blackbyre Limestone. One of the outstanding features that may be noticed here is the wonderful state of preservation which the corals present when seen under the microscope, such genera as *Lithostrotion* and *Lonsdaleia* often exhibiting the internal structural details of the corallite in perfection, the dissepiments, septa, tabular vesicles, columella, and other details being clearly distinguishable. The same may be said of a band of solitary corals which has been traced through the various quarries that have been opened from time to time in the Beith neighbourhood, and which have yielded a large number of species referable to the genera already noticed.

Undoubtedly the echinoderms played the most important rôle as rock-forming agents during the Carboniferous epoch, and occur abundantly in the Blackbyre Limestone, the crinoids being particularly large; portions of the limestone, consisting almost entirely of the aggregated remains of the joints and cirri of stems and arms, and plates of the calyx. They are probably referable to the genera *Allagecrinus*, *Platycrinus*,

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Parisocrinus, *Scaphiocrinus*, *Poteriocrinus*, and *Ulocrinus*, which have been determined as amongst the more common forms found upon this horizon. The crinoidal fragments vary in size, from the minute ossicles of the fingers up to joints of the stem, which in some specimens from Trearne measure over an inch in diameter. Under the microscope sections of the ossicles exhibit an areolar structure comparable with that of living cells, having their walls thickened with calcareous material, a structure which is similar to that found in the test of the echinoidea and other echinodermata. As a rule, however, little of their original structure can be made out, and, microscopically, they cannot be said to be of great interest.

Fragments of the plates and spines of *Archæocidaris urei* can be found in many of the thin sections, and in specimens from Hillhead and Cunningham-Baidland they are rather abundant in a bed of white limestone lying on the same horizon as the polyzoan bed of Trearne. At Thorn, Carluke, there occurs a bed near the top of the Blackbyre Limestone about 2 inches thick which is entirely built up of fragments of *Archæocidaris*. The plates, spines, and portions of the dental apparatus have become completely disunited, and have become arranged in the stratum according to their specific gravity, some of the thin layers being made up almost entirely of the smaller ambulacral plates and secondary spines, while other layers consist only of the larger plates, spines, and heavier portions of the dental apparatus.

Although not so important as the crinoids and corals, the bryozoa are very plentiful, and form the main mass of some of the beds, especially of the white limestone of Trearne. They belong almost entirely to the *Cyclostomata*, and are occasionally in a fair state of preservation, as in the case of the white bands near the top of the Blackbyre Limestone just referred to. As a rule, however, they occur in a more or less fragmentary condition, usually consisting of detached zoœcia, associated with crinoidal remains, and cemented together in a matrix of clear calcite. Certain of the bands in the Blackbyre Limestone consist essentially of the zoœcia of bryozoa. One remarkable band was noticed by Dr. John Young as occurring in the Blackbyre Limestone of Trearne and other localities in North Ayrshire containing fragments of the

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bryozoan form, first discovered in the Devonian rocks of Ontario and Scotland, and named by Professor Nicholson and R. Etheridge, jun., *Ascodictyon*. The late Dr. John Young (1895, p. 142), gives a very clear summary of this interesting little organism which he and other workers had been familiar with by sight for a period of twenty years. Its true place in the zoological scale had baffled such investigators as Dr. Strethell Wright, Mr. H. B. Brady, and even the redoubtable Professor Huxley. It was reserved for the sagacity of the late Mr. G. R. Vine to point out that in all probability their true relationship, even if not identical, at least was very close to the modern ctenostomatous bryozoan as represented by such forms as *Valkeria*. In point of time *Ascodictyon* ranges from the Silurian to the Carboniferous Limestones, and its geographical distribution includes Canada, the United States of America, and Great Britain. It is found encrusting stems of encrinites, as well as the more robust forms of bryozoans, such as *Fenestella*, *Glauconome*, and *Polypora*. The creeping stolons or rootlets are clearly adherent with the zoœcia-bearing branches, erect or free. The oval or elongate zoœcia are apparently without distinct openings. They are very abundant in certain slides, and in the mature stage were thought to be decidious. In size they vary between $\frac{1}{35}$ and $\frac{1}{60}$ of an inch in length by about half that in breadth. The transparent sections prepared by Dr. Young have the cells plentifully scattered all over the slides, but in few, if any, of them can a point of attachment be clearly seen. This is only what might be expected, as the rubbing down would sever all connections which were not in the same plane. The interesting fact emerges in the examination of these slides that *Ascodictyon* cells appear to be more numerous in certain dark parts of the section containing *Mitcheldeania* than in others.

The Blackbyre Limestone is usually succeeded in the west of Scotland by a remarkable bed of ashy mud, to which reference has already been made. It rests upon the irregular hummocky tip of the limestone, and varies considerably in thickness from point to point. After the elevation of the limestone into a land surface, a forest of sigillaria appears everywhere to have been established upon it. This was again succeeded by a slight submergence, and a deposit of ashy mud with fish

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remains of an estuarine character was formed. Fragments of teeth, bones, scales, and plates are distributed throughout the ashy-like groundmass, and associated with them are numerous ossicles of crinoids, the centres of which have been filled in with the ashy material. Sections of this bed when seen under the microscope are brilliantly coloured, and exhibit a great deal of interesting structural phenomena.

It is not my intention to discuss here the bearing which the occurrence of *Girvanella* and *Mitcheldeania* in association with the characteristic D2 fauna of the Bristol area has as a basis for the correlation of the two areas. That I hope to discuss in more detail in a future paper dealing with the Blackbyre fauna as a whole. The following remarks dealing more particularly with the distribution of the calcareous algæ may, however, be permitted.

The specimens of *Mitcheldeania nicholsoni* originally described by Mr. Wethered were obtained by him from Wadley's Quarry, near Drybrook, Mitcheldean, where they occur in the Lower Limestone shales near the bottom of the series. Professor Silby has traced this algal layer for a considerable distance, and he has come to the conclusion that it represents the top of K3 of the Bristol sequence. He also refers to the existence of *Mitcheldeania* on a higher horizon corresponding probably to the base of C2. It is in the north of England and along the Scottish Border that we meet with the most remarkable development of this reef-building alga. Over extensive areas in north Cumberland and the east of Roxburgh we find *Mitcheldeania* upon two horizons, an upper lying immediately below the Fell Sandstone, and a lower one in the middle of the underlying series of limestones and shales. It is of interest to note, as Professor Garwood points out, that though *Mitcheldeania* forms the basin of this reef-like development, there is also found in association with it minute tubule of *Girvanella* with coarser tubes, reminding one of the *Sphærocodium* deposit of Gothland.

The upper horizon from which Nicholson obtained his type specimens of *Mitcheldeania gregaria* occurs a short distance below the Fell Sandstone of Northumberland and the Scottish Border, in the well-known limestone of Kershopefoot and Kidd's Linn. This limestone is extensively composed of the bullet-

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shaped or grape-like skeletons of this peculiar calcareous organism. It is estimated that this layer must have originally been deposited over an area of at least 1000 square miles. It is considered to be upon the C zone of the Bristol area and contemporaneous with the Whitehead Limestone of Mitcheldean.

Professor Garwood thinks that the identity of the Mitcheldean and Scottish Border horizons is still further strengthened by the following evidence. In the beds underlying the *Mitcheldeania gregaria* band in North Cumberland there occur certain calcareous nodules largely made up of the tubes of *Serpulæ*. These are absent in the Westmoreland district. But Professor Silby has recorded them from the Lower Limestone shales containing *Mitcheldeania* in the Forest of Dean district. The fact that the upper algal layer in Northumberland and along the Scottish Border is overlaid by the Fell Sandstone has also been regarded as lending additional support to the view that these widely separated areas are upon the same stratigraphical horizon.

In attempting to trace the relationship of the *Girvanella* and *Mitcheldeania* horizons of the west of Scotland with that of the Scottish Border and north of England, it is necessary, in the first place, to follow the Blackbyre Limestone from the east of Scotland into Haddingtonshire. We have elsewhere recently adduced a considerable body of evidence which goes to show that the second Longcraig Limestone exposed on the shore east of Dunbar is the same as the Blackbyre Limestone of the west of Scotland. In the year 1898 the late Mr. William Gunn, of the Geological Survey, showed that the group of the Lower Limestones about Dunbar and round the Midlothian coalfield does not represent any part of the mountain limestone of Yorkshire, but is the equivalent of the upper part of the Yoredale Series of Phillips, which were included by him in the Millstone Grit. He identified one of the Longcraig Limestones, or perhaps the set of them (it does not seems quite clear which), as the equivalent of the Eelwell Limestone of north Northumberland and the Five Yards Limestone of Weardale and Teesdale. Drs. Peach and Horne (1903, p. 836) regard the Gilnockie Limestone of Eskdale and Liddesdale as the equivalent of the Eelwell of Berwick and Northumberland, and they both lie on a much higher stratigraphical

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horizon than the Kershopefoot Limestone. It would appear therefore that both *Girvanella* and *Mitcheldeania* have a pretty wide range in the Lower Carboniferous Limestones. As we have seen, the lower of these two horizons has been identified with the C zone of the Bristol sequence, while the upper has been regarded as the equivalent of the D2 zone of that district. Professor Garwood considers the *Girvanella* nodular band to be upon the Upper Dibunophyllum zone horizon of the Bristol area. In the present state of our knowledge of Carboniferous stratigraphy and palæontology we consider it particularly undesirable that too much reliance should be placed upon these correlations of so widely distant areas. For though there is a close resemblance between the faunal assemblages it is quite possible that these do not indicate anything more than a similarity of physical conditions of deposition. A consideration of all the evidence that has been adduced goes to show that the algal growths and these faunal associations indicate certain definite physiographical conditions similar to those which exist at the present day in the neighbourhood of coral reefs. There is abundant evidence in the west of Scotland that such lagoon conditions obtained during the period represented by the Lower Carboniferous Limestone Series when the existing land surface was undergoing continual subsidence or elevation. I am indebted to the kindness of Mr. Robert Garry for the photographs accompanying the paper.

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EXPLANATION OF PLATE.

Fig. 1. Girvanella, sp., Blackbyre Limestone, Law Quarry, Dalry. Slide $\frac{01\text{-}53}{\text{bqs.}}$ × 50.

Fig. 2. Girvanella, sp., Blackbyre Limestone, Trearne, Beith. Slide $\frac{01\text{-}53}{\text{bqr.}}$ × 100.

Fig. 3. Mitcheldeania, sp., Blackbyre Limestone, Trearne, Beith. Slide $\frac{01\text{-}53}{\text{bur.}}$ × 50.

Fig. 4. Ascodictyon, sp., Blackbyre Limestone, Trearne, Beith. Slide $\frac{01\text{-}53}{\text{cas.}}$ × 50.

Fig. 5. Foraminifera, Girvanella and other Structures, Cunningham Baidland, Dalry. Slide $\frac{01\text{-}53}{\text{bqa.}}$ × 100.

Fig. 6. Crinoids, Fish Bones, and Scales in Ashy Mudstone, Blackbyre Limestone, Trearne, Beith. Slide $\frac{01\text{-}53}{\text{bwc.}}$ × 50.

All in the Young Collection, Kelvingrove Museum, Glasgow.

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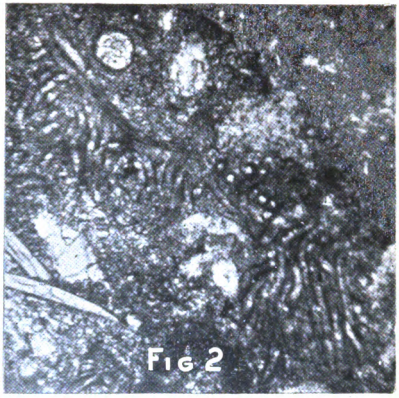

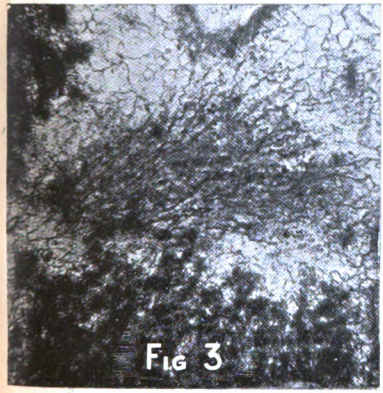

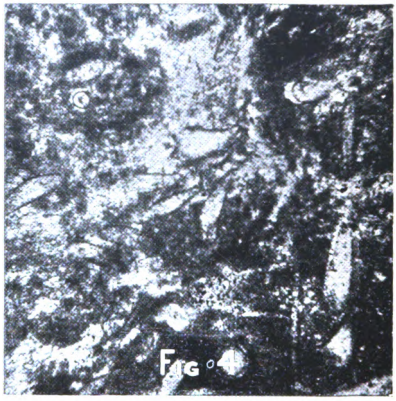

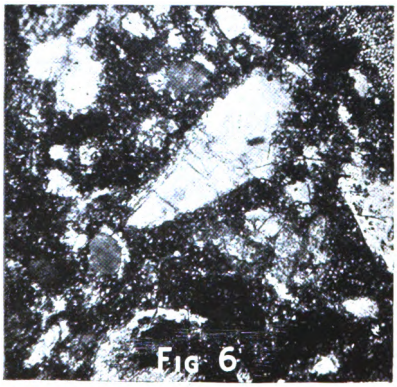

R. Garry, B.Sc., Photo.

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PROCEEDINGS OF THE GEOLOGICAL SOCIETY OF GLASGOW

SESSION 1916-1917.

Fifty-Ninth Session.

SOCIETY'S ROOMS, 207 BATH STREET, 12TH OCTOBER, 1916.

The first meeting of the fifty-ninth Session was held here this evening—Mr J. NEILSON in the chair.

The Minutes of the last meeting were read and adopted.

Mr. D. N. MacArthur, B.Sc., 28 Grafton Street, Glasgow, proposed by Miss A. T. Neilson and Mr. L. Hawkes, was elected an Ordinary Member.

Mr. G. W. TYRRELL exhibited, on behalf of Mr. B. K. N. Wyllie, a number of "Stone-Age Artifacts from Northern Ashanti." These are of three types. (*a*) Rough chips and flakes of quartz; (*b*) chisel or celt shaped polished stones; (*c*) artifacts with a herring-bone or cross pattern. The first two types are common throughout the Gold Coast Colony, but the third is rare, the specimens exhibited being found at Temma, 100 miles north of Coomassie, in a remarkable natural stronghold. The latter consisted of a rectangular block of current-bedded sandstone, 200 to 300 yards long by 100 yards broad, and nearly 200 feet high, standing with sheer walls on the low slope at the side of a wide valley. The patterned objects and the celts were found on the floor of a small cirque inside this, which may have been adopted as a fortress or a fetish monastery by an earlier race of inhabitants; the local Ashantis display utter ignorance of the originators of these things, and their fetish methods are totally different. A piece of iron slag was also found inside the cirque. Professor J. W. Gregory thought that four of the quartz flakes showed undoubted signs of human workmanship, but it was impossible to say whether the others were natural or not. The incised stones are the most interesting. The pattern is that largely used on the Benin bronzes, and he remembered having seen the same type of pattern in some of the collection of the Zimbabwe period in Rhodesia. There is reason to think that an Iron Age in Africa preceded the Bronze Age, and it is possible that the iron slag belonged to the same period. Mr. Neilson agreed that some of the chips were undoubtedly of human workmanship, and that they were typically neolithic. Several of them seemed to show percussion structures. Mr. Ludovic Mann remarked on the fact that all the patterned objects were apparently broken, and suggested that as they seemed to be burnt they might have been used in some furnace operations.

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Dr. C. H. DESCH read a paper, illustrated by lantern slides and specimens, on "The Origin of Agates." The most puzzling question in regard to agates was, he said, the parallel banding of the chalcedony of which they were chiefly composed. This had usually been regarded as representing successive flows of liquid containing gelatinous silica, which was deposited in thin layers on the walls of the cavity in which the agate was formed. Certain features common in agates were regarded as "tubes of entry" or "tubes of escape." In 1867 Ruskin had brought forward evidence to show that the banding was rather due to segregation in the solid state, but no theory as to the mechanism of the process could then be given. The work of Liesegang on rhythmical precipitation in gelatinous masses had led to the production of objects in which all the characteristic features of agates, including the "tubes of escape," were exactly imitated by processes of simple diffusion. It was not even necessary to assume precipitation. Slides were shown to prove that rhythmical crystallisation, giving rise to a banded structure, could be observed even in pure substances. It was sufficient to assume a process of rhythmical crystallisation in a mass of gelatinous silica to account for the banding and other characteristic features of agates.

In the discussion which followed Mr. G. W. TYRRELL pointed out that agates were more common in the older lavas, the more recent ones containing calcite, zeolites, &c. Mr. L. HAWKES observed that a parallel state of things exists in Iceland, where the agates are confined to the Tertiary rocks, the vesicles of the Glacial and recent lavas being often empty.

J. W. GREGORY.

SOCIETY'S ROOMS, 207 BATH STREET, 9TH NOVEMBER, 1916.

The second meeting of the fifty-ninth Session was held here this evening—Prof. J. W. GREGORY in the chair.

The Minutes of the previous meeting were read and adopted.

The following were elected Ordinary Members of the Society:—Lady M'Robert, B.Sc., Douneside, Tarland, Aberdeenshire, proposed by Mr. Ludovic Mann and Mr. H. R. J. Conacher; Miss Hepburn, 693 Great Eastern Road, Glasgow, proposed by Mr. P. A. Leitch and Dr. A. Scott.

The following reports of the work of the previous Session were submitted and unanimously adopted:—Council report, by Mr. Peter Macnair and Mr. H. R. J. Conacher, Joint Hon. Secretaries; financial report, on behalf of Mr. E. Hall Wight, Hon. Treasurer; Library report, by Mr. Wm. Sinclair, Hon. Librarian.

The following office-bearers were elected:—

Vice-President (for three years)—Mr. G. W. Tyrrell, A.R.C.Sc., F.G.S., proposed by Mr. H. R. J. Conacher and Dr. A. Scott.

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Hon. Secretary (for one year)—Mr. A. Scott, M.A., D.Sc., proposed by Mr. M. Macgregor and Mr. J. Neilson.

Hon Treasurer (for one year)—Mr. D. Smith, proposed by Mr. J. Neilson and Mr. D. B. Duncanson.

Members of Council—Mr. J. L. Begg, proposed by Mr. D. Smith and Dr. A. Scott; Mr. C. R. Cowie, proposed by Mr. Wm. Sinclair and Mr. D. B. Duncanson; Mr. P. A. Leitch, proposed by Dr. A. Scott and Mr. D. Smith; Mr. T. Wise, proposed by Mr. A. Shanks and Mr. D. Chalmers.

Prof. J. W. GREGORY, D.Sc., F.R.S., delivered the Presidential address on "The Mineral Phosphates and the Conservation of Mineral Resources." [See *Transactions*, vol. xvi., pp. 115-63.]

JAS STARK.

SOCIETY'S ROOMS, 207 BATH STREET, 14TH DECEMBER, 1916.

The third meeting of the fifty-ninth Session was held here this evening—Mr. J. STARK in the chair.

The Minutes of the previous meeting were read and adopted.

Mr. H. R. J. CONACHER read a paper on "Oil Shales and Torbanites." [See *Transactions*, vol. xvi., pp. 164-92.]

Mr. JAMES NEILSON read a paper on "The Auld Wives' Lifts: An Ancient Monument." [See *Transactions*, vol. xvi., pp. 193-202.]

J. W. GREGORY.

SOCIETY'S ROOMS, 207 BATH STREET, 11TH JANUARY, 1917.

The fourth meeting of the fifty-ninth Session was held here this evening—Prof. J. W. GREGORY in the chair.

A. A. Hagart Speirs, Esq., D.L., J.P., Elderslie, proposed by Messrs. J. M. Campbell and P. Macnair, was elected a Life Member.

Mr. J. NEILSON read an obituary notice of Mr. Livingstone, and it was resolved that the President should send a letter of condolence to the relations.

A motion, proposed by Messrs. Tyrrell and Leitch, that £10 of the Society's funds be voted for the purposes of the Library during the current Session, was carried unanimously.

Mr. C. R. COWIE gave notice that at the next meeting he would move that Mr. J. Renwick be elected an Honorary Associate.

The adjourned discussion of Mr. H. R. J. Conacher's paper on "Oil Shales and Torbanites" was continued. Prof. J. W. GREGORY expressed his appreciation of the work, with the main conclusions of which he cordially agreed. He said that although the structure of the so-called yellow bodies showed that they were not organic, very little was known regarding their composition. In their cryptocrystalline

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nature they resembled sphærocrystals of inulin, and also the forms which result from the solidification from solution of cellulosic materials. They seem to have developed *in situ*, growing by replacement of the groundmass. He referred to the common co-occurrence of calcite with these bodies, and suggested the possibility of their formation by precipitation following the neutralisation of humic acid solutions.

Mr. COWIE stated that the insolubility of the yellow bodies did not militate against their resinic nature, as resins tended to become less soluble as their age increased. Further, some resins yielded olefines and paraffins on distillation, the yield increasing with the pressure.

Dr. SCOTT suggested that the determination of the setting point was too subjective to give results of scientific value, and that it might be substituted by determination of the viscosity. The estimation of the ash also presented difficulties owing to the possible loss of sulphur dioxide by the oxidation of pyrites, and of carbon dioxide by the ignition of calcium carbonate. In general this work seemed to be in agreement with the results obtained by Wheeler and Jones in the case of coal, where the source of the hydrocarbons lies in the resinic portions. The phenols, however, constituted a difficulty, as it is held that their absence from petroleum points to the non-vegetable origin of the latter, while resins, on distillation with fused caustic soda, yield characteristic dihydroxybenzene derivatives. It would be interesting to try this latter test in the case of oil shales, particularly as pyrocatechuic acid had been obtained from lignites by similar treatment.

Mr. MACLAURIN pointed out that the agreement between the proportions of yellow bodies and oil did not hold in the case of the Wheatrigg coal, which, on distillation, gave a high proportion of phenolic bodies. In general, the amount of phenols given by shales was low, but was higher in the case of cannel coal, and this pointed to the resins in the former being of somewhat different nature, and possibly resembling gums.

With regard to the points raised by Prof. Gregory, Mr. CONACHER said calcite, or chalybite, is sometimes abundant in oil shales, but it had not occurred to the writer that it played any essential part in their formation, and it was by no means of constant occurrence in torbanites, although occasionally plentiful. With regard to the growth of the yellow bodies *in situ*, he considered that when one of the individuals was seen to cross the bedding planes it was merely an indication of its hardness, and the occurrence of close groups of individuals, whose outlines conformed to one another, might be due to the shattering of a piece of resin, the fragments remaining together, and subsequently having the structures induced in them. Professor Gregory's experiments in the artificial production of the yellow bodies were extremely illuminating, but one would like to know whether the precipitates obtained would yield the right products on distillation. The fact that the distillation of resin under pressure resulted in the production of paraffins was new to the author, but he had pointed out

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that under prolonged distillation at normal pressure the products tended steadily towards the paraffin type. It was admitted that the setting point of a crude oil was not a very satisfactory guide as to the quality, but it was simply a handy index when taken along with other characters. In the case of the Wheatrigg parrot coal the discrepancy between the micro-contents and the experimental yield might be due to variation in the original nature of the resin present, or to the degree of metamorphism undergone.

While no attempt had been made to deal with the problems presented by natural petroleum, it had occurred to the author that this might be claimed as some ground for suggesting that possibly resin, remaining as the sole relic of a vanished vegetation, had been the source of the petroleum in at least some degree.

J. W. GREGORY.

SOCIETY'S ROOMS, 207 BATH STREET, 1ST FEBRUARY, 1917.

The fifth meeting of the fifty-ninth Session was held here this evening —Professor J. W. GREGORY in the chair.

The Minutes of the previous meeting were read and adopted.

On the proposal of Messrs. C. R. Cowie and J. Stark, Mr. J. Renwick was elected an Honorary Associate, with all the privileges of an Ordinary Member. Mr. A. Henry, 11 Clifford Street, Ibrox, proposed by Messrs. Neil and Tyrrell, was elected an Ordinary Member.

The President intimated that Mr. R. G. Carruthers had been awarded the Bigsby Medal by the Geological Society of London, in recognition of his researches in Scottish geology and palæontology.

The discussion of Mr. J. Neilson's paper on "The Auld Wives' Lifts" was continued. Prof. J. W. GREGORY pointed out that the structure shows a much greater resemblance to a tor than to a cromlech. He admitted the glacial moulding of the surrounding surface, but held that the amphitheatre was pre-glacial, as the direction of its drainage was across that of the ice. Mr. J. RENWICK maintained that the "Lifts" could not be classed as a dolmen, as the latter were erected for use as burial places and had much larger chambers. Similarly it could not be likened to a menhir, as the top stone could not be raised in the way the latter are supposed to have been erected. While the legends and superstitions show that the trilith had been used for religious purposes, it probably originated through the action of frost in the joint planes of the local sandstone. The absence of other blocks in the immediate neighbourhood is probably due to their use in building dykes, as there is good reason to believe that a very large block near the "Lifts" was broken up for this purpose a number of years ago.

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Mr. NEILSON agreed that the hollow was natural, but objected to a pre-glacial origin for it, as a tor would certainly have been swept away completely during glacial times. The stones themselves are not glacial, and were erected by human agencies. With regard to Mr. Macnair's suggestion that the problem of its origin might be settled by excavations, in order to determine whether the rock surface on which the trilith rests was glaciated or not, he did not think that this was necessary, as it seemed a fair inference that the glaciated nature of the surrounding rock surfaces extended to that underlying the "Lifts."

Mr. G. W. TYRRELL exhibited on behalf of Mr James Scott a number of ancient stone implements from Nigeria, and their resemblance to the neolithic types found in Britain was indicated.

Mr. STARK exhibited an old "glass" bottle which had been so completely devitrified that it was now almost entirely crystalline.

Mr. MACNAIR showed a collection of fossils from the Gallowhill Limestone, and a fine slab containing numerous species of Posidonomya becheri from Calderwood Glen, East Kilbride.

J. W. GREGORY.

SOCIETY'S ROOMS, 207 BATH STREET, 8TH FEBRUARY, 1917.

The sixth meeting of the fifty-ninth Session was held here this evening—Professor J. W. GREGORY in the chair.

The Minutes of the previous meeting were read and adopted.

Professor GREGORY and Mr. C. R. COWIE proposed a motion to the effect that Sections III. and V. of the Constitution be altered as follows:—

Section III.—Members.—The Society shall consist of Ordinary Members, Resident and Non-Resident Honorary Members, Corresponding Members, and Associates.

Section V.—Honorary Members and Corresponding Members.—In 1st paragraph delete "Honorary Associates." Substitute all after 1st paragraph by—

"Persons who are not ordinarily resident in Scotland and who are distinguished by their attainments in Geology or allied Sciences shall be eligible for election as Non-Resident Honorary Members.

"Persons who are ordinarily resident in Scotland and who have helped the Society by the contribution of original communications, or by services rendered as office-bearers or in any other way, or who are distinguished by their attainments in Geology or allied Sciences, shall be eligible for election as Resident Honorary Members.

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"Persons who are ordinarily resident at a distance from Glasgow, and who may be willing to communicate papers or render other service to the Society, shall be eligible for election as Corresponding Members.

"All Honorary Members, whether Resident or Non-Resident, shall be entitled to all the privileges of Ordinary Members. Corresponding Members shall be entitled to attend all meetings of the Society, lectures and excursions, but shall have no vote in the management of the Society's affairs, nor be entitled to receive gratis copies of the *Transactions*, except at the discretion of the Council.

"The number of Non-Resident Honorary Members shall not exceed twenty, and the number of Resident Honorary Members shall not exceed ten."

After some discussion, this was unanimously agreed to.

Mr. J. L. BEGG read a paper by Dr. F. A. Bather, F.R.S., on "Two New Species of Carboniferous Crinoids." [See *Transactions*, vol. xvi., pp. 203-19.]

Professor J. W. GREGORY, D.Sc., F.R.S., read a paper on "Thomson's Genera of Scottish Carboniferous Corals." [See *Transactions*, vol. xvi., pp. 220-43.]

Mr. J. V. HARRISON, B.Sc., read a paper on "The Bennan Sill." This sill, which is intrusive into the New Red Sandstone at Bennan Head, South Arran, belongs to the type of composite sills, some of which have already been described from Skye and Bute. It consists generally of three layers, an upper one of dolerite, a thick mass, in the middle, of quartz porphyry, and a lower layer of dolerite. In places a fourth layer, consisting of a fairly intimate mixture of the acid and basic rocks, is found. The dolerites contain numerous xenocrysts of quartz and felspar, generally surrounded by a reaction rim of a pyroxenic nature. The hypersthene which is present is probably due to a reaction between the orthosilicate molecules of the dolerite and the free silica of the xenocrysts. The acid rocks have been basified, as they contain numerous xenoliths of the basic material. The groundmass is often glassy, and this glass probably approximates to orthoclase in composition. The petrology of the rocks was discussed shortly, the peculiar phenomena of acidification and basification being also described. The age of the sill can be definitely determined as early Tertiary, as it cuts Mesozoic sediments, and is in turn intruded by the late Tertiary dykes. One interesting intrusion consists entirely of tachylyte, which is about 6 inches thick.

Mr. TYRRELL remarked on the similarity of this sill to the great Tertiary sill of South Bute. In reply to Dr. Scott, Mr. HARRISON announced his adherence to the hybrid-rock theory in connection with the origin of the sill, and pointed out the physical chemical difficulties in the way of the liquation theory.

JAS. STARK.

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SOCIETY'S ROOMS, 207 BATH STREET, 8TH MARCH, 1917.

The seventh meeting of the fifty-ninth Session was held here this evening—Mr. J. STARK in the chair.

The Minutes of the previous meeting were read and adopted.

Mr. J. R. Thomson, Auchinlea Estate Office, Cleland, Lanarkshire, proposed by Messrs. P. A. Leith and A. Scott, was elected an Ordinary Member.

Mr. G. W. TYRRELL read a paper on "The Igneous Geology of the Cumbraes." [See *Transactions*, vol. xvi., pp. 244-74.]

A paper on "The Intrusions of North-West Renfrewshire," by Mr. P. A. Leitch and Dr. A. Scott, was read. [See *Transactions*, vol. xvi., pp. 275-89.]

Mr. R. S. HOUSTON read a paper entitled, "Notes on Some Renfrewshire Minerals." Those described included malachite, chalcocite, chalcopyrite, and native copper. The chalcopyrite is remarkable for the high percentage of iron sulphide.

G. W. TYRRELL.

SOCIETY'S ROOMS, 207 BATH STREET, 12TH APRIL, 1917.

The eighth meeting of the fifty-ninth Session was held here this evening—Mr. G. W. TYRRELL in the chair.

The Minutes of the previous meeting were read and adopted.

Mr. R. Macmillan, M.A., B.Sc., 22 Eglinton Terrace, Ayr, proposed by Messrs. G. W. Tyrrell and A. Scott, was elected an Ordinary Member.

Mr. G. V. WILSON read a paper entitled, "Notes on the Geology of Mull." A brief description of the structure of the island was given, and the distribution of the Pre-Kainozoic rocks pointed out. In Kainozoic times a great sequence of lava flows was poured out; in the north and west areas these are fresh olivine basalts, but in the south-east, within a circle passing through Salen, Craigmure, and Lochbuie, the basalts are much altered and baked. Within a smaller circle round the head of Glenmore lavas of the pillowform variety are also found. These are thought to have been deposited in the caldera of an old volcano. A few interbedded sediments occur sporadically through the whole lava series, and these include the famous plant-bed of Ardtun. This great series of lava flows has been folded into a set of anticlines and synclines in south and central Mull, but in the west it is flat, and gives rise to a terraced country. Large masses of gabbro and granophyre have also been intruded at various periods, some being probably connected with the folding, and others being definitely later. In central Mull large patches of volcanic breccia occur in the crater of the old volcano. Besides the large intrusive masses, central Mull is riddled with "inclined sheets," having a concentric arrangement,

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and dipping inwards at an angle of about 50 degrees. Two sets occur with slightly different foci, and the later can be seen cutting through the earlier. Another kind of concentric intrusion, "ring-dykes," is also found; these consist of vertical, circular dykes of gabbro and granophyre, which in some cases occur along fault-lines, good examples being seen near the head of Glenmore. In addition to the intrusions already mentioned, the whole area is cut by a great series of N.-W. and S.-E. basalt dykes, which may be regarded as the last phase of volcanic activity in the island. The paper was illustrated by a large number of lantern slides.

Mr. P. MACNAIR read a paper on the "Microscopical Characters of the Blackbyre Limestone." [See *Transactions*, vol. xvi., pp. 290-304.]

G. W. TYRRELL.

SOCIETY'S ROOMS, 207 BATH STREET, 10TH MAY, 1917.

The ninth meeting of the fifty-ninth Session was held this evening—Mr. G. W. TYRRELL in the chair.

The Minutes of the previous meeting were read and adopted.

Mr. A. Harker, M.A., F.R.S., St. John's College, Cambridge, proposed by Messrs. Tyrrell and Scott, was elected a Non-Resident Honorary Member.

At a meeting of the Geological Society a paper entitled "Notes on Some Ancient Volcanic Glasses," by Mr. P. Macnair and Dr. A. Scott, was read.

Mr. PETER MACNAIR also read a paper on "The Fauna of the Lower Carboniferous Limestone Series," in which he pointed out that this group of strata in the West of Scotland contained eight well-marked calcareous horizons which were characterised by definite faunal associations. The lowest of these, the Hollybush Limestone, is rich in corals and brachiopods, and shows near the top a band almost entirely composed of *Rhynchonella pleurodon*. This is succeeded by the Blackbyre Limestone, which presents much the same palæontological features as the underlying Hollybush Limestone, and has immediately over it a bone bed, a lamellibranch bed, and a brachiopod bed. The characteristic form of this horizon is *Sanguinolites abdenensis*, which occurs in great numbers. The succeeding Hurlet Limestone is an encrinital limestone, which, though not richly fossiliferous, contains certain brachiopods, and sometimes a band of the Foraminifer *Saccamina carteri*. One of the richest and most characteristic of all the horizon is that which lies above the Blackhall Limestone, *Spirifer Urei* being the characteristic species, and occurring in great numbers. The next limestone in ascending order is the Main Hosie Limestone, which is characterised by the abundance of corals, echinoderms, and bryozoa which it contains. In ascending

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order the next recognisable faunal association is that associated with the Calderwood Cement Limestone. Here we have an estuarine and marine type in association, the former represented by the shales containing *Posidonomya corrugata*, scales, plates, and bones of fishes of an estuarine character, and land plants, the marine type by the cement limestone, full of brachiopods and other purely marine forms. The highest of these fossiliferous bands, known as the top marine band, carries a varied fauna, and is characterised by a bed of shale, which is simply a mass of *Lingula Squamiformis* and *Nucula gibbosa*.

CHAS. A. HALL.

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ABSTRACT

OF THE

TREASURER'S ACCOUNTS.

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ABSTRACT OF THE TREASURER'S ACCOUNTS FOR THE YEAR ENDED 30TH SEPTEMBER, 1916.

CASH ACCOUNT.

RECEIPTS.

To Subscriptions:—			
Ordinary Members (including 8 new Members)—132 at 10/, ...	£66 0 0		
Do. (including 3 New Members)—6 at 7/6, ...	2 5 0		
Do. Arrears—3 at 10/, ...	1 10 0		
Life Member, ...	5 5 0		
		£75	0 0
,, Interest on Funds, ...	.. ..	9	2 6
,, Do. Mr. Cowie's Donation, ...	.. ..	3	6 11
,, Investments Realised:—			
Bond with Campbeltown Corporation under Mortgage, at 3½ per cent., ...	£170 0 0		
,, Do. at 3¾ per cent.—Mr. Cowie's Donation,	100 0 0		
		270	0
		£357	9 5

EXPENDITURE.

By Balance due Hon. Treasurer, 30th Sept., 1915,		£17 1 1			
Less Cash on Hand—Accrued Interest on Mr. Cowie's Donation, ...		1 13 1		£15	8 0
,, *Transactions*:—					
Printing and Publishing Vol. XV., Part 3 (1914-15), including cost of illustrations and Authors' Copies of Papers, ...		£74 18 5			
Postages and Outlays, ...		2 0 5			
		£76 18 10			
,, *Less*:—					
Donation from Publisher, ..	£5 5 0				
Grants from Carnegie Trust for Illustrations, ...	16 18 8				
Glasgow University for Copies of Papers, ...	6 2 9				
Authors for extra Copies of Papers,	3 4 4				
Mitchell Library for 40 Copies, ..	3 2 3				
Hon. Librarian for Sales of Copies and 2 Jubilee Volumes,	0 19 8				
		35 12 8		41	6 2
,, Library:—					
Bookbinding and Magazines, ...				1	7 3
,, Subscription to Marine Biological Association, 1916, ..				1	1 0
,, ,, to Palæontographical Society, 1916, ...				1	1 0
,, Mr. Cowie's Donation:—					
Glasgow University, Interest to Martinmas, 1915, ...		£1 13 5			
Royal Technical College, Interest to Martinmas, 1915, ...		1 13 5		3	6 10
,, Administration:—					
Printing and Postage of Cards, Excursion Booklets, and Advertising, ...		£10 18 8			
Rent, Insurance, and Attendance, ...		12 0 6			
Disbursements by Hon. Secretaries, Postages, Stationery, and Petty Expenses, ...		2 15 9		25	14 11
,, Investments:—					
Three 6 per cent. Exchequer Bonds of £50 each, repayable 16th February, 1920, ..		£150 0 0			
Two 5 per cent. Exchequer Bonds of £50 each, repayable 1st December, 1920, ...		100 0 0		250	0 0
,, Cash in Bank on Deposit, ...		15 0 0			
,, Do. in Hon. Treasurer's Hands, ...		3 4 3		18	4 3
				£357	9 5

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ABSTRACT OF THE TREASURER'S ACCOUNTS FOR THE YEAR ENDED 30TH SEPTEMBER, 1916.

LIFE SUBSCRIPTION ACCOUNT.

Sept. 30, 1916.—To Balance to Credit, ...	£193	0	0	Sept. 30, 1915.—By Balance from last Account, ...	£187	15	0
				Sept. 30, 1916.— ,, New Subscription, ...	5	5	0
	£193	0	0		£193	0	0

Mr. CHARLES R. COWIE'S DONATION.

Sept. 30, 1916.—To Glasgow University, one-half of Interest to Martinmas, 1915, ...	£1	13	5	Sept. 30, 1915.—By Balance from last Account, ...	£101	13	1
,, The Royal Technical College, Glasgow, one-half of Interest to do., ...	1	13	5	Sept. 30, 1916.— ,, One year's interest to Whitsunday, ...	3	6	11
Balance to Credit, ...	101	13	2				
	£105	0	0		£105	0	0

BALANCE SHEET.

To Life Subscription Account, ...	£193	0	0	By Investments:—						
,, Mr. Charles R. Cowie's Donation and accrued Interest, ..	101	13	2	Three 6 per cent. Exchequer Bonds of £50 each, repayable 16th February, 1920, ..	£150	0	0			
,, Capital Account,*	473	11	1	Two 5 per cent. Exchequer Bonds of £50 each, repayable 1st December, 1920, Mr. Cowie's Donation, ...	100	0	0			
								£250	0	0
				,, Property:—						
				Books in the Library, ...	£440	0	0			
				Furniture, Bookcases, Microscope, &c., ..	60	0	0			
								500	0	0
				,, Cash in Bank, ...	£15	0	0			
				,, Do. in Hand, ...	3	4	3			
								18	4	3
	£768	4	3					£768	4	3

* NOTE.—Subject to cost of publishing *Transactions*.

GLASGOW, 31*st October*, 1916.—Examined, compared with relative Vouchers and Securities, and found correct, the Balance in Treasurer's h nds being Three Pounds Four Shillings and Three Pence.

ALEXANDER M'LEAN
ARCH. MACINTYRE } *Auditors.*

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THE GEOLOGICAL SOCIETY OF GLASGOW.

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1902. Lapworth, Charles, LL.D., F.R.S., 38 Calthorpe Road, Edgbaston, Birmingham

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1900. Gray, Mrs. Robert, 59 George Street, Edinburgh.

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1907. Murdoch, Mrs. J. B, Capelrig, Newton Mearns, Renfrewshire.

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1917. Renwick, John, 9 Crosbie Street, Maryhill.

1909. Smith, John, Dykes, Dalry, Ayrshire.

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Year of Election.

1864. Mitchell, Rev. Hugh, LL.D., Craig, Montrose.
1867. Kerr, David, Wemyss Colliery, Fifeshire.
1871. Jack, R. L., LL.D., F.G.S., 36 Overstrand Mansions, Battersea Park, London.
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1884. Nathorst, Professor Alfred Gabriel, Stockholm, Sweden.
1898. Livingston, Colin, Ardtraigh, Fort-William.
1909. Young, James, Lesmahagow.
1916. Black, Geo. F., New York Public Library, New York, U.S.A.

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1905. Anderson, E. M., M.A., B.Sc., H.M. Geological Survey Office, 33 George Square, Edinburgh.
1882. Anderson, James, 3 Herschell Street, Great Western Road, Glasgow.
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1912. Brodie, Matthew S., 39 Wellmeadow, Paisley.
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1914. Brown, A. J., Hope Street, Glasgow.
1914. Brown, James, Broomside, Manse Road, Motherwell.
1914. Brown, John, 78 Hill Street, Kilmarnock.

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1904. Buchanan, R. M'Neil, M.B., C.M., F.F.P.S.G., Corindi, Scotstounhill, Glasgow.

1894. Burnett, Sir John James, R.S.A., LL.D., 70 University Avenue, Hillhead, Glasgow.

1902. Burns, Professor Daniel, M.Inst.M.E., Technical College, George Street, Glasgow.

1907. Campbell, A. G., Artesian Works, Inchicore, Dublin.

1877. Campbell, John MacNaught, 6 Franklin Terrace, Sandyford, Glasgow.

1906. Carruthers, R. G., F.G.S., H.M. Geological Survey Office, 33 George Square, Edinburgh.

1895. Chalmers, David, 3 Winston Avenue, Broomhill, Glasgow.

1914. Chambers, R. S., Carbarns, Jerviston Road, Motherwell.

1912. *Conacher, Harry R. J., Horsewood Road, Bridge of Weir.

1891. Cowie, Charles R., Woodend, Partickhill, Glasgow.

1900. *Cozens, Samuel F., Salem, Skelmorlie.

1894. Dixon, Walter, Derwent, 30 Kelvinside Gardens, Glasgow.

1916. Dollin, P. E., 24 Watson Avenue, Rutherglen.

1907. Donald, W., The Eglinton Silica Brick Company, Ltd., Dundyvan, Coatbridge.

1881. *Dougan, John, 27 Smith Street, Hillhead, Glasgow.

1887. Dow, William, 101 Stanmore Road, Mount Florida, Glasgow.

1895. Dron, R. W., M.Inst.C.E., 65 Renfield Street, Glasgow.

1913. Duncanson, David B., B.Sc.(Lond.), 19 King Edward Road, Jordanhill, Glasgow.

1883. Dunlop, Robert, Woodmill Road, Dunfermline.

1914. Dunn, George Loudon, Annanhill, Kilmarnock.

1914. Dunn, H. Shaw, 40 Highburgh Road, Dowanhill, Glasgow.

1901. Du Toit, Alex. L., B.A., F.G.S., Geological Commission, South African Museum, Cape Town, S.A.

1914. Edwards, E. J., M.Sc., Royal Technical College, Glasgow.

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1901. Faill, John, 7 Winton Drive, Kelvinside, Glasgow.
1911. Falconer, J. D., M.A., D.Sc., F.G.S., F.R.S.E., Lecturer on Geography, The University, Glasgow.
1914. Feeley, Wm., 127 Glebe Street, Glasgow.
1898. Fergus, A. Freeland, M.D., 22 Blythwood Square, Glasgow.
1915. Fletcher, W., West View, Scott Street, Hamilton.
1915. Fraser, J. M., 169 Berkeley Street, Glasgow.
1898. *French, Thomas, 1 Kelvinside Terrace, Kelvinside, Glasgow.
1914 Fyfe, D. W., 11 Melrose Gardens, Glasgow

1901. Gale, William M., C.E., 18 Huntly Gardens (West), Glasgow.
1887. Gardner, John, 65 Great Clyde Street, Glasgow.
1912. Gilchrist, Percy C., 18 Priory Road, Hornsey, London.
1908. Gilmour, Matthew B., Saffronhall House, Hamilton.
1873. *Gilmour, Thomas, M.D., Port Ellen, Islay.
1895. Glen, Alexander, 25 Dumbreck Road, Glasgow.
1877. *Graham, M. M., 21 Bath Street, Glasgow.
1904. *Gregory, John Walter, D.Sc., F.R.S., F.G.S., Professor of Geology, Glasgow University.

1907. Hall, Rev. Charles A., F.R.M.S., Meersbrook, Meikleriggs, Paisley.
1915. Hamilton, James, 53 Bothwell Street, Glasgow.
1913. *Harrison, John V., B.Sc., 34 Rowallan Gardens, Glasgow.
1916. Hawkes, Leonard, M.Sc., Eversleigh, Stowe Park Avenue, Newport, Mon.
1908. Hendry, David, Dunmore, Thomson Avenue, Johnstone.
1917. Henry, Archibald, 11 Clifford Street, Ibrox, Glasgow.
1912. Herdsman, W. H., 144 Wellington Street, Glasgow.
1903. Hill, Alexander, 11 Dolphin Road, Pollokshields, Glasgow.
1877. Hislop, George R., F.C.S., F.R.S.E., Greenhill House, Paisley.
1891. Hodge, William, 27 Montgomerie Drive, Kelvinside, Glasgow.
1897. Houston, Robert S., Meadowside, Glasgow Road, Paisley.
1914. Howat, William, The Cottage, North Motherwell.

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1894. Hubbard, Walter Raglan, 9 Broomhill Avenue, Partick, Glasgow.

1908. Hunter, George, M.Inst.M.E., Mining College, Wigan.

1901. Hunter, William, Rosemount, Ledard Road, Langside, Glasgow.

1903. Hurll, Mark, Redholm, Temple.

1911. *Innes, Peter, 5 Ibrox Place, Paisley Road (West), Glasgow.

1912. Jack, Thomas, Blackhall, Brookfield, Johnstone.

1915. Johnston, J. J. Hunter, Oakfield, Lenzie.

1901. Kemp, William, c/o Mrs. Brown, 1 Kelvinside Terrace (West), Glasgow.

1908. Kerr, Andrew C., c/o Carron Company, 125 Buchanan Street, Glasgow.

1908. Kerr, David, Lynnewood, 140 Bo'ness Road, Grangemouth.

1890. Kidston, Robert, LL.D., F.R.S., 12 Clarendon Place, Stirling.

1882. King, Hugh B., Solicitor, Kilwinning.

1882. King, Robert C., Solicitor, Ledcameroch, Kilwinning.

1907. *Knight, James, M.A., D.Sc., F.R.S.E., F.G.S., F.C.S., St. James's Public School, Calton, Glasgow.

1916. Leitch, Colin M., 223 New City Road, Glasgow.

1908. Leitch, P. Arthur, Ardgowan Square, Greenock.

1914. Lewin, Harry W., Civil and Mining Engineer, 154 West Regent Street, Glasgow.

1916. MacArthur, D. N., B.Sc., 28 Grafton Street, Glasgow.

1896. M'Cowan, Donald, Dundashill House, Port-Dundas, Glasgow.

1899. M'Creath, George W., M.E., 208 St. Vincent Street, Glasgow.

1904. M'Creath, William, C.E., M.Inst.M.E., 208 St. Vincent Street, Glasgow.

1901. M'Culloch, Andrew, 11 West Regent Street, Glasgow.

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1908. M'Donald, David P., M.A., B.Sc., S. A. School of Mines and Technology, Johannesburg.

1898. M'Gavin, Alex., 10 Lothian Gardens, Kelvinside, North Glasgow

1867. M'Glashan, John, 114 Candleriggs, Glasgow.

1910. M'Gregor, Murray, M.A., B.Sc., H.M. Geological Survey, 33 George Square, Edinburgh.

1904. Macintyre, Arch., F.S.A.A., Muirbrow Chambers, Hamilton.

1877. Maclay, Bailie William, F.G.S., Thornwood Hall, Langside.

1894. Maclay, James, M.A., LL.B., Ferndean, Garelochead.

1903. M'Lean, Alexander, 466 St. George's Road, Glasgow.

1917. MacMillan, Robert, M.A., B.Sc., 22 Eglinton Terrace, Ayr.

1895. Macnair, Peter, F.R.S.E., F.G.S., Art Galleries and Museum, Kelvingrove, Glasgow.

1897. *M'Neil, Charles, 1 University Gardens, Glasgow.

1914. M'Queen, David P. H., 7 Stewartville Gardens, Wishaw.

1916. M'Robert, Lady, B.Sc., Douneside, Tarland, Aberdeenshire.

1914. M'Vean, Duncan A., M.A., 28 Stewartville Street, Partick.

1883. M'Whirr, John, J.P., 3 St. John's Road, Cathcart, Glasgow.

1887. Main, John, F.G.S., 24 Marlborough Avenue, Partick.

1894. Mann, Ludovic M'Lellan, F.S.A.(Scot.), 144 St. Vincent Street, Glasgow.

1902. Menzies, James R., 72 Lauderdale Gardens, Hyndland Glasgow.

1915. Miller, Alfred G., West View, Strathmore Road, Hamilton.

1881. Mitchell, G. A., 5 West Regent Street, Glasgow.

1904. Moore, Quintin, Garrowbank House, Riddrie.

1877. Moore, Robert T., D.Sc., C.E., 142 St. Vincent Street, Glasgow.

1916. Morrison, Miss M., 40 Rhannan Road, Cathcart, Glasgow.

1908. *Morrison, James, 87 East Princes Street, Helensburgh.

1889. Motherwell, A. B., Rosemount, Airdrie.

1900. *Muirhead, John, 13 St. John's Drive, Pollokshields, Glasgow.

1898. Munro, Alexander, 2 Royal Crescent, Queen's Park, Glasgow.

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1894. *Murdoch, Robert, 91 Maxwell Road, Pollokshields, Glasgow.
1907. *Murdoch, J. A. W., Capelrig, Dunblane.
1870. *Murray, David, LL.D., 169 West George Street, Glasgow.
1907. Murray, Andrew G., c/o Brownlie, Watson & Beckett, 225 West George Street, Glasgow.

1907. Neilson, Miss Agnes T., 41 West Cumberland Street, Glasgow.
1891. Neilson, James, 53 Wellshot Drive, Cambuslang
1894. *Neilson, James, 116 Bishop Street, Port-Dundas, Glasgow.
1898. Nimmo, David, 17 Duke Street, Hamilton.

1869. *Orr, John, 12 Newhall Terrace, Glasgow.

1915. Patton, Donald, M.A., B.Sc., Manse Villa, Pollok Road, Shawlands, Glasgow.
1891. Pollok, Arthur, Kirkland, Bonhill, Dumbartonshire.
1910. Preston, Frank A. B., 16 Waverley Park, Shawlands, Glasgow.
1910. Priestly, H., 8 Glenview, Paisley.

1873. Rankine, David, C.E., 238 West George Street, Glasgow.
1902. Reoch, James W., 22 Montgomerie Street, Kelvinside.
1911. Roberts, J. G., Trees Cottage, Barrhead.
1914. Robinson, P. J., A.M.Inst.C.E., Moverons, Allanshaw Street, Hamilton.
1910. Romanes, Mrs. J., Broompark, Helensburgh.
1875. *Rottenburg, Paul, LL.D., Holmhurst, Dowanhill Gardens, Glasgow.

1912. Scott, Alexander, M.A., D.Sc., 137 St. Andrew's Road, Pollokshields, Glasgow.
1897. Shanks, Arch., 5 Green Lodge Terrace, Greenhead, Glasgow.
1893. *Sharp, John Grant, 127 Great Hamilton Street, Glasgow.
1910. Shute, Arthur E., 4 Holyrood Crescent (West), Glasgow.
1887. *Sinclair, William, 47 Oswald Street, Glasgow.
1889. Sloan, Samuel, M.D., 5 Somerset Place, Sauchiehall Street, Glasgow.

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1911. Smellie, Wm. R., M.A., D.Sc., Mayfield Villa, Mossend.
1908. Smith, Duncan, F.F.S., Laurelbank, Arkleston Road, Paisley.
1912. Smith, John, 5 Whitehaugh Drive, Paisley.
1887. *Somerville, Rev. James E., B.D., Castellar, Crieff.
1871. *Sommerville, Joseph, 40 Montgomerie Street, Kelvinside North, Glasgow.
1902. Spencer, James S., Glassingall, Dunblane, Perthshire.
1917. *Spiers, A. A. Hagart, D.L., J.P., Elderslie, Renfrewshire.
1896. Stark, James, 13 Princes Gardens, Partick, Glasgow.
1881. Steel, James, 37 Prince Edward Street, Crosshill, Glasgow.
1912. Stevens, Alexander, M.A., B.Sc., Fresgoe, Reay, by Thurso.
1916. Stewart, Miss E., 16 West Princes Street, Glasgow.
1906. Stewart, Robert D., Belinda Cottage, Hillview Street, Shettleston, Glasgow.
1878. Stewart, Thomas, St. George's Chambers, Cape Town, South Africa.
1911. Stewart, W. Wylie, B.Sc., 312 West Princes Street, Glasgow.
1891. Stirling, David, 10 Cook Street, Glasgow.
1916. Sutherland, A., 12 Regent Park Terrace, Strathbungo.
1914. Sutherland, J. R., M.Inst.C.E., Engineer's Office, 45 John Street, Glasgow.

1897. Thomson, Henry, 10 Princes Square, Strathbungo, Glasgow.
1917. Thomson, John R., Auchinlea Estate Office, Cleland, Lanarkshire.
1916. Trench, Miss J. B., M.A., B.Sc., 1 Springfield Terrace, Crossmyloof, Glasgow.
1906. Tyrrell, G. W., A.R.C.Sc., F.G.S., Geological Department, Glasgow University.

1907. Waddell, A. W., M.E., 18 Kensington Gate (West), Glasgow.
1912. Walker, James Grahame, Glencairn, Alder Road, Hillpark, Glasgow.
1910. Watson, George C., 65 Chapel Street, Maryhill, Glasgow.
1914. Weir, Thomas M., 224 St. Vincent Street, Glasgow.
1915. Weir, Walter, Calder Ironworks, Coatbridge.
1901. Wight, E. Hall, 150 Hope Street, Glasgow.

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Year of Election.

1916. Wingate, John B., 208 St. Vincent Street, Glasgow.

1909. Wise, Thomas, Blackwood, Miller Street, Hamilton.

1912. Wordie, James M., B.A., B.Sc., 52 Montgomerie Drive, Glasgow.

1881. Wotherspoon, David, 1108 Argyle Street, Glasgow.

1910. Wright, James, 36 Douglas Street, Kirkcaldy.

1911. Wyllie, B. K. N., M.A., B.Sc., Newmains, Caerlaverock, Dumfriesshire.

1902. Young, Arch. A., 2 Parkgrove Terrace (West), Glasgow.

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TRANSACTIONS

OF THE

GEOLOGICAL SOCIETY OF GLASGOW.

No. XVI.—The Origin of the Auld Wives' Lifts and the Whangie. By James Stark.

The interest aroused by recent papers (Gregory, 1916; Neilson, 1917) on the Auld Wives' Lifts may well excuse further discussion of the problem of their origin. From their imposing appearance it was altogether natural that legends should have gathered round them, and that they should have been regarded as a monument of the burial or religious customs of a long past age. But to say the least of it, it is unlikely that the primitive inhabitants of Scotland could, for any purpose, have brought together three such huge rock-masses, and lifted the heaviest of the three, an unwieldy block of 20 tons weight, on top of the other two. If a cromlech, there is nothing else in Scotland to compare with it, the nearest approach being probably the menhir or standing stone, of which the greatest example may weigh as much as 10 or 12 tons. To transport and erect such a stone would be comparatively an easy task. It is scarcely relevant to cite instances of megalithic monuments of great size in more highly favoured and further advanced countries than Neolithic Scotland, whose ungenial climate and barren hills constituted a barrier in the way of primitive civilisation, and denied to her sparse population the mechanical skill and the liesure for tasks of such magnitude.

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The accounts of prehistoric structures in other countries are often exaggerated. In his recent paper on the Auld Wives' Lifts Mr. Neilson (1917) gives the dimensions and weights of the capstones of four Irish cromlechs, on the authority of Borlase, and in all four cases, if the dimensions are correct, the weights are grossly exaggerated. The largest one is said to be about 100 tons, whereas, even if it were a square-hewn block, it would only be 69 tons. The cubical content of the capstone of the Auld Wives' Lifts is only 58 per cent. of a square-hewn block of the same dimensions. In the same proportion the weight of the Irish block would only be 40 tons, and who shall say that the dimensions are correct when there has been such a gross misstatement about the weight? From the figures given by Borlase, it would therefore appear that the capstone of the Lifts is very much heavier than that of any cromlech in the United Kingdom, so that, if the lifts are artificial, by far the greatest feat in cromlech building has been accomplished by the least advanced people of these islands. Futhermore, the supporting stones of a cromlech are usually pillar-stones of quite moderate dimensions, leaving room for a burial chamber under the capstone, whereas, in the Lifts, the two lower stones together probably weigh at least as much as the capstone, and are close together, if not overlapping, at the base, which indeed cannot be seen, being buried under about 2 feet of moss, which has grown up around them.

We are all agreed that the three stones comprising the Lifts have been derived from the coarse-grained sandstone which forms the natural amphitheatre to the N.W., and that other masses of this rock have been detached from the escarpment along joints, by the ordinary processes of denudation, though, for the most part, remaining close to their original positions; indeed it is by this means that the escarpment itself has been formed. This action would be greatly intensified during the Glacial Period, and the detached fragments mostly ground up and carried away by the ice, the main stream of which, as indicated by the glaciated surface of the rock where exposed on the moor above, flowed from the north-west, across the edge of the escarpment. During the amelioration of the climate, at the end of the Glacial Period, there must have been frequent partial melting and regelation of the ice, which would not only open

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a pre-existing joint, but would force the detached mass further and further from its parent rock, until it became enveloped in the general ice stream. It would then be carried along for just such a distance that, through the continued improvement of the climate, the ice would never again be powerful enough to transport it further.

Applying this to the problem of the Lifts, the two lower stones are roughly triangular in section, and are inclined towards each other, the west one at an angle of about 45 degs., and the east one considerably less. Mr. Neilson says, "The two bottom stones seem to have come from the same stratum, and are very much false bedded. I think the west stone is in its natural position, while the upper surface of the east stone requires to be lifted up so that it is horizontal in order to bring it to a corresponding position. They contain bands of conglomerate which can be traced through both stones." In this I agree with him. If the east stone were lifted over the west one the conglomerate shown in both stones would form a continuous band. More than that, the upper surface of the east stone would then just about fit into the lower surface of the capstone. which is strong evidence that the three stones of the Lifts were torn from the escarpment as a single block 15 to 16 feet high, with a parting of soft shale about 7 feet from its upper surface, and a diagonal joint, or small fault, crossing the block at an angle of about 45 degs.

It is well known that a glacier or ice stream flows with a differential motion, being faster on the surface than at the bottom, where it is retarded by friction, and also, in this case, by the lower part of the block being under the lee of the escarpment. The tendency would thus be to shear off the upper portion of a tall block embedded in the ice, and the block destined to form the Lifts accordingly seems to have given way along the soft shale parting, which would have but little cohesion with the sandstone. The weight of the upper portion of the block would then rest mainly on the east side of the lower portion, and would force it to slip downward along the diagonal joint, until the face which had been next to the joint became the base of the block, as shown in the accompanying figure. As the upper portion of the block, now the capstone, thus forced the divided sections of the lower portion further and

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further apart, it settled down between them, so that its lower surface is now only about 4 feet above the surface of the moss, or about 3 feet below its original level. In doing so it appears to have slid down the inclined surfaces of the two sections fairly equally, so that it still retains its original horizontal position.

It has been objected to the ice theory that there are no glacial marks on the stones of the Lifts, but if these were simply enveloped in the ice stream they could not be glaciated, except on the bottom where they were dragged over the underlying rock—the top was probably glaciated before the block was moved from its parent bed. Another objection has been made that there is no glacial dèbris in the neighbourhood of the Lifts. This could accumulate only in the immediate lee of the escarpment, where there would be an ice-fall due to the sudden drop of some 16 feet. As a matter of fact, there are several boulders protruding through the moss in that direction, and there are probably many others entirely covered.

In this way I submit that the Auld Wives' Lifts may be accounted for without attributing their erection to human agency, which to the rude and barbarous aborigines of Scotland in the Stone Age would be next to impossible.

The origin of the Whangie has also been the subject of recent discussion. Mr. Tyrrell (1916) has questioned the previously held view that it was due to a slice or whang of one of the old lava beds of Calciferous Age slipping downwards along the weathered and crumbling surface of the underlying sedimentary beds; and he conducted an excursion last summer to settle the point.

It is only where the rock has been sufficiently compact to resist weathering that the projections on one side of the gorge fit the hollows on the other. For the most part, masses of the rock have fallen from both sides, and fill up the bottom of the gorge, but where the original surfaces of the fracture still remain the detached portion, that is, the Whangie itself, appears, in some places, to be somewhat lower and in others somewhat higher than its original position, while it must be admitted that, owing to the talus of dèbris outside, and fallen portions of the rock inside the gorge, the condition of the subjacent strata cannot be ascertained.

It seems at least possible, then, that the detachment of the Whangie may be due to the same causes that detached the Auld

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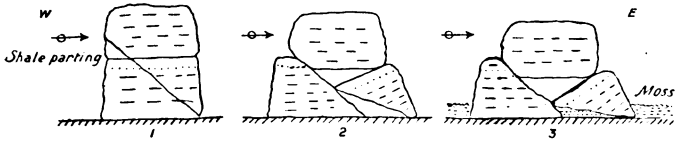
Wives' Lifts, viz., the alternate partial melting and freezing of ice in an original joint or fissure, only in this case, as the rock face looks towards the west, the direction of the ice flow would prevent the mass of detached rock being carried any further.

The present width of the chasm at the bottom varies from about 4 feet to about 10 or 12 feet, while it is everywhere much wider at the top. Its average depth may be 35 to 40 feet. The Whangie itself is fissured and fractured at various places along its length of about 350 feet, so that it now consists rather of a series of separate bosses and pinnacles than a continuous wall. So great a mass of rock could hardly have been detached by any agency without such fractures taking place, and subsequent weathering has been so great as to suggest a very remote date for its original detachment, probably as far back as the Glacial Period.



Stages in the Evolution of the Auld Wives' Lifts.

1. Block detached from escarpment. 2. Intermediate position with east portion of lower part of block sliding down diagonal joint. 3. Final position. Arrow indicates direction of ice-stream.

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No. XVII.—Occurrence of Iron Ore in Millstone Grit Lava, Ayrshire. By R. W. Dron, F.R.S.E.

In 1895 Mr. John Smith (Trans. Geol. Soc., Glasgow, 10, 133, 1895), contributed a paper to this Society, describing a deposit of volcanic ash in Ayrshire, containing bands of ironstone. During the following twenty years there was practically nothing done in the way of further exploration of these deposits until the urgent demand for a supply of ironstone in this country led Mr. G. V. Wilson, of the Geological Survey Office, Edinburgh, to make a careful inspection of this horizon.

The volcanic zone referred to lies immediately below the base of the Coal Measures Series, and is now considered to be of Millstone Grit age. The average section of Millstone Grit, as exposed in North Ayrshire, is as follows:—

Bauxitic clay, - - - - - -	3 to 9 feet.
Series of lava flows with interbedded sediments, - - - - -	70 to 180 ,,
Monkcastle fireclay, - - - -	0 to 20 ,,
Sandstone, - - - - - - -	0 to 20 ,,
Sandy fireclays, and blaes with marine fossils, and occasionally thin limestones, - - - - -	0 to 20 ,,

The lava flows are often much decomposed and altered by processes similar in many ways to lateritization, whereby their iron contents has been proportionately increased by the abstraction of silica and alumina. This type of alteration is most common near the top of the series, although in a section at Glenburn it can be observed that the basal flow is also affected. The line of the outcrop can be traced from the shore at Saltcoats north-eastwards by Stevenston and Kilwinning, and thence circling round by Montgrennan and Kilmaurs, along the northern edge of

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the Kilmarnock coalfield. At several points along this outcrop beds containing a fair percentage of iron were found, but of these the only one which appeared to hold out much prospect of economic use was exposed in the Quarrel Burn, near Brockleheugh (Breakplough, on the Ordnance Survey maps), about a mile north east from Stevenston. Here Mr. Wilson discovered a bed four feet thick outcropping in the stream. A sample from this outcrop gave the following analysis :—

Iron,	42·43	per cent.	
Si_2O_2,	15·00	,,	} 24·80 insoluble.
Al_2O_3,	9·80	,,	
MnO,	·46	,,	
CaO,	·46	,,	
MgO,	·28	,,	
Moisture,	1·16	,,	
Loss on Ignition,	11.50	,,	
Phosphorus,	·061	,,	
Sulphur,	·020	,,	

The outcrop was in a faulted area where extensive mining was impracticable.

Following on this discovery the writer was instructed to prosecute a vigorous search to ascertain if the seam extended over a sufficient area to justify the development of an ironstone mine. A considerable number of bores and trial pits were put down in the area between Brockleheugh and Ardrossan. The results unfortunately were not such as to justify the further prosecution of the scheme, but it is desirable to place the information on record, as a time may come when the technical and commercial aspects of the question may be such as to warrant the reconsideration of the subject.

A full section of the strata was obtained by means of a diamond bore at a point 500 yards south-west from the Brockleheugh outcrop. The borer's journal gave the following section :—

1	Coal (Raise Coal),	2	10
2	Fused fakes and fireclay,	—	
3	Calmy blaes,	1	0
4	Parrot coal,	0	8
5	Fused fireclay,	3	9

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6	Parroty blaes,	0	3
7	Dark fireclay,	0	2
8	Coal,	0	3
9	Dark blaes,	1	6
10	Ironstone rib,	0	4
11	Parroty blaes,	0	3
12	Coal,	0	4
13	Fused fireclay,	11	4
14	Volcanic ash,	6	0
15	Red ash,	0	5
16	Grey ash,	1	6
17	Red ash,	8	9
18	Grey ash,	10	1
19	Green ash,	7	6
20	Soft dark blaes,	1	0
21	Fused fireclay,	2	0
22	Fakes and coal,	0	7
23	Grey fakes,	0	6
24	Fused fakes and fireclay,	2	4
25	Ironstone rib,	0	1
26	Dark red ash,	2	0
27	Green ash,	8	0

The "Red ash," No. 17, appeared to correspond with the bed found at the outcrop. Analysis for iron were made of each foot of this bed with the following results :—

		Iron.	Insoluble.	Loss on Ignition.
1	Top 3 inches,	21·61	50·30	15·80
2	Next 12 „	19·21	44·30	15·90
3	„ 12 „	17·95	40·40	14·50
4	„ 12 „	19·02	44·20	13·60
5	„ 12 „	24·75	42·50	12·80
6	„ 12 „	11·97	51·80	14·30
7	„ 12 „	17·69	45·50	13·50
8	„ 12 „	20·79	46·30	15·10
9	„ 12 „	16·69	51·50	13·70
10	„ 6 „ (bottom),	15·43	51·50	16·30

The average of these figures is 18·5 per cent. of iron and 46·8 insoluble. Comparing these with the original analysis of 42 per

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cent. in a seam 4 feet thick, it will be observed that the total quantity of iron in the 8 feet 9 inches seam is about the same as in the 4 feet seam, and the greater thickness is made up by a larger admixture of silica, alumina, &c. By crushing a sample and washing out the foreign matter Mr. Wilson was able to obtain an analysis showing 49·5 per cent. iron and 7·8 per cent. insoluble.

As there was still some prospect of finding an ore body of value to the country under the exceptional conditions due to the war, several trial pits were put down to locate the outcrop, but the results were inconclusive. In one case what appeared to be the ore body was discovered, but it contained only 13 per cent. of iron. Subsequently a bore was put down as near the Brockleheugh outcrop as possible. The following is an extract from the borer's journal :—

1	Coal (Raise Coal Seam),			——	
2	Fused fakes and fireclay,	3	feet	5	inches.
3	Dark fakes,	3	,,	9	,,
4	Fused fireclay and balls,	11	,,	0	,,
5	Grey volcanic ash,	4	,,	0	,,
6	Grey volcanic ash with balls,	2	,,	9	,,
7	Grey volcanic ash,	11	,,	4	,,
8	Dark blaes,	1	,,	0	,,
9	Fireclay,	1	,,	6	,,
10	Black blaes,	0	,,	9	,,
11	Dark fakes and blaes,	2	,,	6	,,
12	Fakey fireclay,	3	,,	6	,,
13	Grey volcanic ash,	0	,,	9	,,
14	Red and grey ash,	2	,,	6	,,
15	Green and grey ash,	7	,,	6	,,
16	Dark grey ash,	3	,,	0	,,
17	Green and grey ash,	1	,,	3	,,
18	Red and green ash,	7	,,	9	,,
19	Red "ore,"	1	,,	7	,,
20	Red and grey "ore,"	1	,,	0	,,
21	Red and grey ash,	0	,,	9	,,
22	Red and grey ore and ash,	4	,,	8	,,
23	Soft green ash,	1	,,	8	,,
24	Limestone,	2	,,	4	,,

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All the ash beds contained iron, varying from 3 per cent. to 29 per cent., and it was difficult to say which, if any, of the beds corresponded with the outcrop as found at Brockleheugh. Between Nos. 15 and 20 there is a body of almost 20 feet thick, containing on an average 20 per cent. of iron. By selecting about 3 feet between Nos. 18 and 20 an average of 25 per cent. of iron can be obtained. In each case the percentage of insolubles was very high.

It was evident from these trials that the ore bodies were too poor and too variable to be of economic value, even under war conditions. It appears that the outcrop at Brockleheugh must be a local enrichment, and similar rich bodies will probably be found scattered throughout the deposit. The theory as to this local enrichment will be dealt with by Mr. Wilson in a subsequent contribution.

The iron ore resources available for Scottish furnaces, which can be imported at reasonable freights, are not by any means inexhaustable. A thick bed, such as above described, may some day be of very considerable importance. Special processes for treatment will doubtless be devised whereby it might be commercially feasible to prepare it for use in the furnaces.

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No. XVIII.—The Igneous Geology of the Ayrshire Coast from Doonfoot to the Heads of Ayr. By G. W. Tyrrell, A.R.C.Sc., F.G.S.

Introduction.

The coast immediately southward from Ayr, including the striking and picturesque double headland of the Heads of Ayr, has attracted little attention from geologists. It is briefly mentioned in the old Survey memoir upon the district by Sir A. Geikie (1869),[1] who later gave a few facts regarding the volcanic vents of the coast in his *Ancient Volcanoes of Great Britain* (1897). W. Burns had previously contributed a short discursive paper to these *Transactions* (1888). The fullest account is contained in a newspaper article by the late R. Boyle describing, in a popular style, the geology of the coast from Ayr to Dunure (1908). Much the same ground had been covered by J. Smith (1895) in a short paper which made a brief mention of the Greenan—Heads of Ayr shore. The same author has also contributed a brief note on the globular shale of the Deil's Dyke to these *Transactions* (1898).

An examination of the coast had long been projected, because the magnificent vertical and horizontal sections exhibited in the Heads of Ayr, of one of the Carboniferous volcanic vents so common in Scotland, seemed to promise much information regarding the mechanism of this type of vent. Unfortunately the sections, good as they are, were disappointing in this respect; but their examination, along with that of other igneous phenomena of this stretch of coast, has yielded a quantity of interesting data, which are presented in this paper.

General Geology.—The coast consists of gently rolling strata of the Cementstone Group of the Calciferous Sandstone at the base of the Carboniferous. These are mostly shales and argillaceous limestones (cementstones), the general dip of which is to the

[1] For literature, see bibliography at end of paper.

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E.N.E. at small angles. The strata are penetrated by the agglomerate vent of the Heads of Ayr, by a dolerite sill (Langhill Point), and by several N.W. to S.E. dykes. Also, interbedded with the strata, there is a thick, lenticular or pod-like, stratified mass of tuff and agglomerate at Greenan. The following notes refer solely to the igneous rocks, which are described in order from south-west to north-east, starting with the N.W. dyke in Bracken Bay immediately south-west of the Heads of Ayr.

Field Relations of the Igneous Rocks.

Bracken Bay.—A dyke of coarse olivine-dolerite with interstitial analcite (crinanite) forms a marked feature on the south side of Bracken Bay. It trends north-west, and has a thickness of 26 feet.

Heads of Ayr.—The Heads of Ayr are built of a mass of agglomerate which probably represents a coalescent pair of volcanic vents. It is exposed in fine horizontal and vertical section along half a mile of coast. Its western side is seen in the sections at the top of the cliff west of Bower Hill (see the 6-inch Ordnance Survey map, Ayrshire, sheet 32 S.E.). An old quarry in the Calciferous Sandstone Series here shows calcareous sandstone and shale dipping 5 degs. in a direction 50 degs. E. of N. These beds pass conformably under stratified agglomerate, which can be followed for a short distance towards the vent proper. The agglomerate is composed mainly of andesite pebbles 2 to 3 inches in diameter, in a finer matrix, but there is also a number of pebbles and blocks of sediments (calcareous sandstone, limestone breccia, shale, &c.) identical in nature with the strata broken through. A few large blocks of indurated cementstone were seen. As far as can be ascertained, the dip of the agglomerate steepens as the edge of the vent is approached, but the actual edge is nowhere exposed. This stratified agglomerate no doubt represents the material spread over the country by the first explosions of the volcanic focus.

At the western edge of the vent proper, where the agglomerate appears at sea-level, the material is still well-bedded, but the beds are in a vertical position. There are here three prominent dyke-like projections, alternating with deep recesses, made up of

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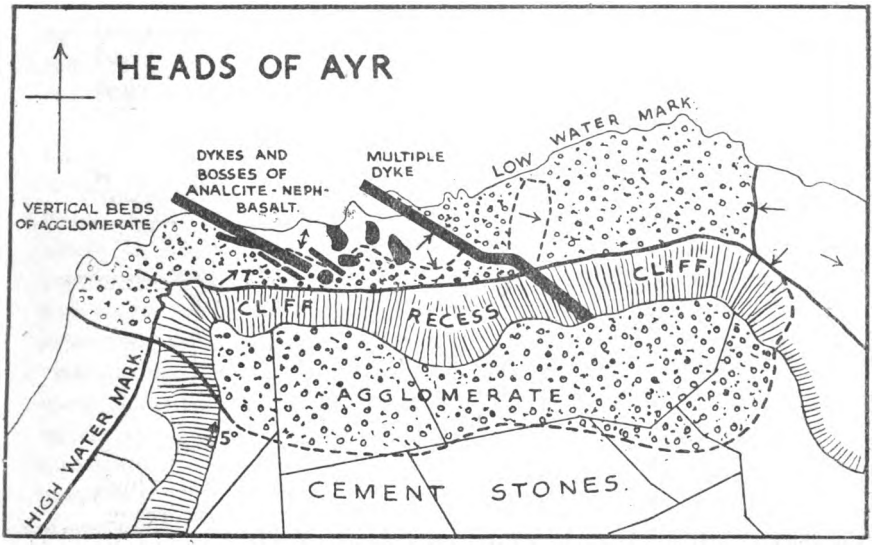
vertical beds of tuff and agglomerate striking in a north-west direction. At this point appear numerous pebbles and boulders of a coarse-grained, white-weathering, ultrabasic, igneous rock (lherzolite), which occur now in all the remaining sections, and appear to mark the main foci of the eruption. These rocks are thoroughly carbonated, and are doubtless the well-rounded limestone pebbles with no fossils referred to by John Smith (1895, pp. 2-3). The agglomerate is of a greyish, greenish, or purplish tint, and consists mainly of andesitic pebbles of fist size, but ranging up to boulders of over a foot in diameter, embedded in a paste of comminuted igneous material. Sedimentary material is comparatively rare in the interior of the vent.

The central recess is a grassed amphitheatre between the two headlands of agglomerate. It is probably caused by the coalescence of the adjacent vents, and by the intervention of Cementstone strata, which are well seen on the foreshore at low tide. These rocks, in spite of minor rolls, dip in general inwards, *i.e.*, to the E. and E.S.E., but in some places the



SCALE — SIX INCHES TO ONE MILE.

Fig. 1.—Geological Map of the Heads of Ayr

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main E.N.E. dip is seen. The disturbances are no doubt due to the position of the beds between closely adjacent vents.

On the foreshore opposite the recess the cementstones and agglomerate are penetrated by several intrusive masses, at least three dykes and five small bosses (see Fig. 1). The westernmost intrusion is a dyke, seen only at low water, which causes a long, straight, rock feature on the foreshore, striking W.N.W. Its width cannot be estimated, but on the western side it throws off a parallel branch 2 feet thick, which has a strongly hæmatised western margin. Nearer the cliff there are discontinuous, lenticular patches, reaching 2 feet 6 inches in thickness, parallel to the main dyke, and probably proceeding from it.

Immediately opposite the recess the strata and agglomerate are penetrated by a 7-feet W.N.W. dyke and five little bosses of analcite-nepheline basalt (Fig. 1). The latter range from 10 feet in diameter to masses about 25 yards in greatest length. They are roughly circular or elliptical in outline.

The eastern side of the recess is bounded by a multiple dyke of olivine-dolerite which cuts visibly through the eastern Head, and passes out to sea as a long scaur. It trends W.N.W., and is divisible into three parts, the two marginal parts composed of a coarse, decomposed, greenish, doleritic rock with a close parallel banding causing a resemblance to stratification. The

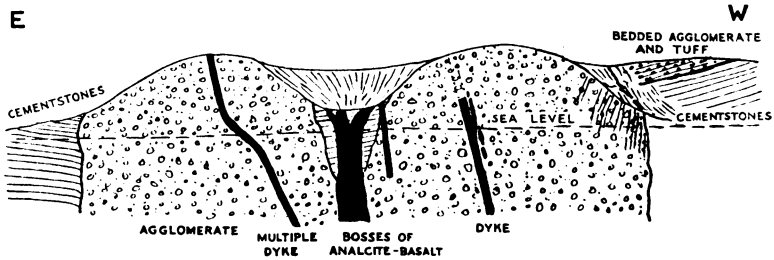

Fig. 2.—Section across the Heads of Ayr from east to west.

central member consists of a much harder blue dolerite, which weathers in a nodular manner, and appears to ramify irregularly in thin vein-like protrusions through the marginal bands. The dyke has a total thickness of 13 feet, of which the central member occupies 4 feet, and the marginal members 4 and 5 feet respectively. It hades 70 degs. to the N.E.

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The agglomerate of the eastern Head has a reddish or purplish colour rather than grey or green, and is perhaps not so pebbly as that of the western Head. This supports the view that the Heads consist of two coalescent vents. The white-weathering boulders and pebbles of lherzolite are, however, quite as abundant in the eastern as in the western Head. The stratification of the agglomerate in the interior parts of both Heads becomes very obscure or non-existent.

At the extreme eastern edge the agglomerate comes up against Cementstone strata on the foreshore which have a decided inward dip (*i.e.*, to the W.); but in the low cliff at the eastern end shales of the Cementstone Series can be seen to dip gently under well-bedded agglomerate, and this material may therefore represent the products of the final explosions of the eruption. The southern margin of the vent may be traced in a rough semi-circle around the back of Bower Hill. It is probable that the focus had originally a more or less circular cross-section about half a mile in diameter, of which about half has been eroded by the sea.

Dykes between the Heads of Ayr and Greenan Castle.—Near Spring Garden Cottage, about half a mile east of the Heads, there is a small basaltic dyke, 2 feet thick, trending almost due east and west.

A quarter mile farther east a long scaur, called the Long Rae[2] stretches out to sea in a N.W. direction. This feature is caused by a pair of N.W. dykes, poorly exposed near low-water mark, and also near high water. The western dyke shows 15 feet of visible thickness, but neither contact is exposed. It consists of alternate bands of fine-grained basaltic and coarse teschenitic rock, striking parallel to the north-west extension of the exposure. Some of the bands are highly vesicular or amygdaloidal. No symmetrical or regular arrangement of the bands, which vary from an inch or two to a foot in width, can be discerned; but the impression remains that the fine-grained and amygdaloidal bands are more abundant towards the centre of the exposure. There are no definite signs of successive intrusion, and it seems probable that the magma was originally heterogeneous, and was emplaced by a single

[2] Long Rue on the six-inch Ordnance Survey Map, but called Long Rae by the natives. See John Smith (1895).

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act of intrusion. A second dyke of precisely the same character is exposed a few yards farther east. Only 4 feet of width is exposed, and no contacts are visible.

A quarter mile N.E. of the Long Rae there is a basaltic dyke, trending N.N.W., forming a shore feature known as Craig Tara. It is 13 feet wide. Another dyke of the same trend, 3 feet wide, occurs halfway between Craig Tara and the Deil's Dyke.

The Deil's Dyke forms a prominent shore feature about a quarter mile west of Greenan Castle. It is a N.W. dolerite dyke, with an overall thickness of 49 feet, including the sedimentary material involved in it. On its eastern side it has branched, and has there included a mass of Cementstone strata with undisturbed bedding. These sediments consist of alternating beds of calcareous sandstone and calcareous shale. In the latter, almost spherical, nodular structures have been developed, which separate out like marbles on weathering. Their diameters range from about half an inch down to microscopic sizes. They are often so thickly sprinkled as to be touching and confluent with one another (John Smith, 1898).

The Greenan Agglomerate.—A large mass of well-bedded agglomerate and tuff is seen on the shore at Greenan Castle, which is perched on the edge of an overhanging cliff of this material. This is clearly of the nature of a thick lenticle interbedded with the Cementstone strata. The dip of the volcanic detritus is E.N.E., conformable with the adjacent sediments, which can be seen both to overlie and underlie it at low tide upon the foreshore. The agglomerate and tuff can be followed along the dip in the old sea cliff at the back of the 25-foot raised beach to the Greenan Farm road. The material varies in grain, but the fragments are mostly of nut size, and consist of volcanic and sedimentary material, with the former predominating. It is comparatively hard, and of purplish-red colour with some grey and green bands. The few cobbles in the agglomerate consist uniformly of mugearite. There are very few large sedimentary boulders, but a slab of cementstone 8 inches long was noticed. The vent from which this material was ejected is not seen in the section. It may be concealed in the unexposed part of the outcrop, or it may now be covered by the sea.

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At Langhill[3] Point, about a quarter mile E.N.E. of Greenan Castle, is a broad area of scattered dolerite exposures on the foreshore, the structural relations of which are obscure, as sedimentary rock is not seen in contact with it. It is too broad and not linear enough to be a dyke; it is more probably a sill interbedded with the strata. The dolerite seen at low water in the River Doon at the mill dam is probably a continuation of this outcrop, as it lies on the same line of strike. The Langhill Point outcrop is cut on its eastern side by a narrow E.-W. dyke of basalt.

A few yards farther E.N.E. a dyke of coarse basalt or dolerite, 25 feet wide, and striking a little west of north, is seen near high-water mark.

Petrography.

The rocks will be described under the following headings:—

1. Agglomerate and tuff.
2. Lavaform pebbles and boulders in the agglomerates.
3. Lherzolite boulders of the Heads of Ayr.
4. Dyke and bosses of analcite-nepheline-basalt, Heads of Ayr.
5. Teschenite dykes of the Long Rué.
6. Olivine-dolerite—crinanite dykes and sill.
7. Tholeiite (Brunton type) dyke.

1. *Agglomerate and Tuff.*—These rocks occur at the Heads of Ayr and at Greenan. They are greenish, bluish-grey, or purplish-red in colour, and consist of a fine-grained paste, in which fragments varying in size from $\frac{1}{4}$ inch in diameter to masses several feet across are embedded. The matrix is relatively abundant, and the included fragments mainly of the smaller sizes. The latter are mostly igneous in character, and sedimentary material, while it occurs, is always very subordinate in quantity to the igneous. At the Heads of Ayr there are numerous cobbles and boulders of carbonated lherzolite in the agglomerate. The larger included fragments are described separately under later headings. In thin section the

[3] Longhill on the six-inch Ordnance Survey map.

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Heads of Ayr agglomerate shows subangular or rounded fragments of vesicular and decomposed andesite, ranging up to ¼ inch in diameter, cemented by an abundant paste of comminuted andesitic debris and crystals. Numerous cavities occur, which are sometimes left vacant, but are more often filled with a coarse mosaic of calcite, or with rosettes of chlorite. An interesting feature is the occurrence of perfectly euhedral crystals of analcite growing out from the margins of the cavities into the surrounding calcite. Owing to the incidence of the plane of section these often appear isolated within the calcite. The larger crystals show good anomalous birefringence recalling that of leucite.

Material other than of igneous origin is rare, except at the extreme margins of the vent, where the agglomerate rests on, or has burst through, Cementstone strata. Here fragments of calcareous sandstone, shale, cementstone, and cherty conglomerate are comparatively numerous. In the thin dyke-like mass of agglomerate between the western margin of the vent and the central recess angular fragments of quartz are somewhat abundant. The matrix of the Heads of Ayr vent may be described therefore as an *andesitic agglomerate.*

The lenticle of agglomerate at Greenan is of a light-green, grey-green, or purplish-red colour, and the rock is rather finer grained than that of the Heads of Ayr, and contains fewer large boulders and pebbles. As described later, practically all the larger fragments are of mugearite. Consonant with this it is seen in thin section that the agglomerate is composed of small rounded fragments of decomposed mugearite embedded in a scanty paste of comminuted material. Calcite, chlorite, and a little of an isotropic colourless material (analcite?) occupy small interspaces. Sedimentary material is in very subordinate quantity, and consists of small angular crystals of quartz and felspar, and a few chips of cementstone and calcareous sandstone. The rock is well bedded, and a few layers are so fine grained and free from large fragments that they are better termed tuff than agglomerate. The Greenan rock is therefore a *mugearitic agglomerate.*

2. *Lavaform Pebbles and Boulders in the Agglomerate of the Heads of Ayr and Greenan.*—The great majority of the

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smaller pebbles in the Heads of Ayr agglomerate consist of olivine-andesites which can be closely matched with the Lower Old Red Sandstone lavas of the Carrick Hills. Some of these rocks, carrying numerous small porphyritic felspars, have a superficial resemblance to the Markle basalts so characteristic of Carboniferous vulcanicity, especially to those types intermediate between Markle and Jedburgh basalts; but they can be easily distinguished in thin section by the comparative paucity of mafic minerals, especially magnetite, in the groundmass. The Carboniferous types have very basic groundmasses especially rich in iron ores, whereas the Old Red Sandstone lavas have a typical felspathic and andesitic type of groundmass in which mafic minerals are in subordinate amount. Basalts do occur in the Carrick Hills which may be hard to distinguish from certain Carboniferous types, but these are comparatively rare (Tyrrell, 1914). Judged by the above criterion the pebbles in the Heads of Ayr agglomerate do not represent products of Carboniferous vulcanicity, although they occur within an unquestionably Carboniferous vent; but they have been derived from the underground continuation of the Old Red Sandstone lavas of the Carrick Hills which outcrop at a distance of three-quarters of a mile, and must be only a few hundred feet below the surface at the Heads of Ayr.

A typical example shows in thin section numerous laths of porphyritic felspar (average size, 4mm. × 1mm.) of acid labradorite (An_{50}) in diverse arrangement, with a few sporadic, hæmatised, and carbonated crystals of olivine, occurring as phenocrysts in a groundmass consisting mainly of small rectangular laths of andesine (An_{40}), with interstitial grains of pyroxene, which are never fresh, but always chloritised and carbonated. Iron ores occur sparsely in small grains, and some interstices are filled with a residuum of brown glassy material, which is in process of devitrification. Another variety differs from the above in the absence of porphyritic felspar and olivine. A third variety is much richer in glassy base.

The only other rock of distinctive character occurring in a large suite of pebbles from the vent is a coarse olivine-dolerite. In thin section this shows rectangular phenocrysts of labradorite, with numerous "serpentinised," carbonated, and

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hæmatised olivines in a coarse, ophitic groundmass of acid labradorite (An_{50}), and augite, now largely replaced by a green serpentinous substance. Iron ores are very scanty except where thrown out of combination by the alteration of the olivine. It is possible that this rock represents one of the basic sills of Old Red Sandstone age which are now exposed in the neighbourhood of Maybole (Tyrrell, 1914, p. 79).

The lavaform pebbles in the agglomerate of Greenan are uniformly mugearites of typical character. They consist of oligoclase microlites with good trachytic texture, interspersed with minute grains of iron ore, and much diffused chloritic decomposition products, probably replacing augite. In this groundmass are enclosed numerous microphenocrysts of serpentinised olivine. The only other features worthy of mention are occasional large amygdales filled with chalcedony, calcite, and "green earths," and a few xenocrysts of quartz, each surrounded by a narrow reaction border.

3. *Lherzolite Boulders in the Heads of Ayr Agglomerate.*—These fragments range from a diameter greater than 12 inches down to pebbles of the size of the fist. They weather smooth and whitish, and contain scattered, greenish-black, shining, cleaved crystals of a pyroxene. In thin section it is seen that in most cases these rocks have suffered extreme carbonation, a large portion of the rocks consisting of a coarse-grained mosaic of calcite and other carbonates, in which are to be found remnants of pale-green diopside and unaltered crystals of deep-brown translucent picotite. The carbonation has proceeded so gradually that the texture of the rock and the characteristic structures of its minerals have been perfectly preserved. The rock may be recognised with a considerable degree of confidence as a typical *lherzolite* consisting of olivine, diopside, enstatite, and picotite. The mesh structure of the olivine is retained in the calcite pseudomorphs, as well as the bastite cleavage of the enstatite. Diopside and picotite are to be recognised from actual remnants which have escaped or resisted alteration. Occasionally a little serpentine is seen, with small mosaics of secondary quartz. This rock may be correlated with numerous other occurrences of ultrabasic igneous rocks found in the Carboniferous vents of Scotland (*postea*, p. 358).

4. *Basaltic Dykes and Bosses of the Heads of Ayr.*—The

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numerous small bosses and dykes intruding the agglomerate between tidemarks in front of the Heads of Ayr consist of a distinctive type of rock presenting the closest resemblance to the analcite-nepheline basalt of Whitelaw Hill, East Lothian (Geol. Surv. Memoir, East Lothian, 1910, pp. 106, 109-11). They are hard, fresh, compact, dark grey to black, basaltic rocks showing an occasional phenocryst of greenish-black olivine or a black lustrous cleavage plane of augite. In thin section they show phenocrysts of fresh olivine and titanaugite in a groundmass consisting mainly of small prisms of augite, with magnetite and biotite, in a pervading base of analcite and nepheline. Both olivine and augite phenocrysts are seriate in size, ranging in the case of olivine from crystals 2 mm. in diameter, and in augite 4 mm., down to tiny crystals mingled with the groundmass. For the most part the olivine is perfectly fresh, and shows good crystal outlines. The augite is also fresh and euhedral, and shows a zonal arrangement of colour, the interiors of the crystals being a pale purple, with a narrow zone of much darker purple upon the margins. Some of the augites have a spongy texture in the interiors of the crystals, due apparently to ill-defined inclusions of groundmass. There are also rounded pseudo-porphyritic masses, ranging up to 2 mm. diameter, or clusters of minute augite grains (*cf.* E. B. Bailey, 1910, p. 109, Pl. X., Fig 2). The groundmass consists chiefly of minute, well-shaped prisms and grains of purplish augite, with subordinate magnetite and a few laths of basic plagioclase felspar embedded in a fresh, colourless, isotropic base. This material has a refractive index well below that of Canada balsam, and, although of cubic cleavage cannot be demonstrated owing to the abundance of apatite needles, there can be no reasonable doubt but that it is analcite. It may also occur in irregularly bounded areas and streaks which may either be free from coloured minerals, or may enclose them in much less abundance than in the groundmass proper. In these areas the analcite becomes yellowish and faintly turbid, but in general does not lose its isotropism. In a few places it is altered to an aggregate of highly polarising zeolites. Some of the areas appear to be bordered by nepheline, the analcite occupying the interiors.

Fresh nepheline may occasionally be detected within the

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analcite areas. It shows rectangular outlines, with a good cleavage and a streakiness due to alteration, parallel to the longer edges of the crystals. It has straight extinction, negative sign in the direction of elongation, and very low double refraction. It is always idiomorphic towards the analcite. In many sections it is decomposed to a micaceous dust.

Biotite occurs in very thin films, much thinner than the thickness of the slide, so that the groundmass minerals generally show through it. It is always grown around a nucleus of iron ore, and thus supports Dr. Alex. Scott's view that these late-formed biotites are due to the interaction of iron ores and hot residual solutions of analcitic composition (A. Scott, 1916, p. 38).

The above is a particular description of the rock from the largest and most seaward boss on the foreshore at the Heads of Ayr. The other occurrences belong to the same general type with small differences in detail. The rocks of the two easterly bosses differ from the above in the absence of biotite. The 7-foot N.W. dyke occurring in connection with the bosses shows some interesting variations. The phenocrysts are entirely of serpentinised olivine, augite being restricted to the groundmass. Associated with the analcite are irregular patches of a colourless mineral of low double refraction, showing mottled polarisation, irregular extinction, refractive index below that of Canada balsam, and a biaxial interference figure. Its characters correspond to those of an alkali-felspar, probably soda-orthoclase. Biotite occurs in the groundmass with the same characters as in the rock described above.

Weathered varieties of these types occur in the 2-foot W.N.W. dyke on the foreshore on the west side of the central recess in the Heads of Ayr. The margins of this dyke are extensively impregnated with hæmatite. The 2-foot N.W. dyke cutting the cementstones on the shore near Spring Garden Cottage, although much decomposed, may also be recognised as belonging to this series.

A specimen taken from the largest boss contains an angular xenolith, about 1 inch in greatest length, green in colour, and looking like an olivine nodule. In thin section it turns out to be an inclusion of lherzolite, consisting mainly of olivine, now almost entirely gone over to yellow serpentine, a pale green

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schillerised diopside, a small quantity of enstatite, and irregular brownish-green grains of some chrome-spinel. Except for its comparative freshness this rock closely resembles the lherzolitic boulders of the agglomerate of the vent.

The closest affinities of the rocks described above are with the analcite-nepheline-basalts and associated monchiquites of East Lothian (E. B. Bailey, 1910, pp. 105-13). They also show considerable resemblance to the analcite- and nepheline-basalts of the Late Carboniferous or Permian province of Ayrshire (Tyrrell, 1912, pp. 126-7). Systematically all these rocks may be included under the general term *ankaratrite*, instituted by Lacroix for melanocratic forms of nepheline basalt (A. Lacroix, 1916).

5. *Teschenite of the Long Rae Dykes.*—This rock is a dark grey-green in colour, mottled with black, and varying in grain size from fine to medium. Parts of the dykes are highly vesicular and decomposed.

In thin section the fresher material is seen to consist mainly of lathy felspars and granular titanaugite. Pseudo-porphyritic serpentinised olivine is rather abundant; irregular grains of iron ore occur in subordinate amount; and large, more or less rounded, cavities are filled with fresh analcite, alkali-felspar, with some biotite and brown hornblende. The texture is hypidiomorphic and medium-grained. The felspar is an unzoned labradorite (An_{60}), and forms elongated rectangular laths which sometimes have a sub-parallel arrangement, and may be tangential to the peripheries of the analcite areas. The titanaugite is of the usual purplish colour with darker margins, and occurs in small subhedral crystals which occasionally have a rough radiate arrangement. The olivine has passed over into a greenish-yellow serpentine with moderate pleochroism and strong double refraction. The iron ore occurs mostly in cuboidal grains, which are usually enclosed within, or close to, the margins of the olivine crystals. Occasionally it forms an intergrowth with titanaugite, and is then skeletal in form. The remaining constituents occur in more or less rounded areas often several millimetres in diameter, which are filled, first, with a broad marginal zone of iron-stained material, probably altered alkali-felspar, riddled with brown pleochroic rods of hornblende, thin leaves of biotite, and grains of iron ore.

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The central spaces are filled with fresh colourless analcite. The iron-stained material is difficult to make out owing to its decomposition and staining, but it polarises irregularly in low tints, and by analogy with other teschenites is regarded as an alkali-felspar, probably soda-orthoclase. These areas represent late infillings of open spaces within the teschenite by residual alkaline liquors.

Some bands in the dykes are considerably finer in grain than the above, and approach the texture of basalts. In these rocks skeletal iron ores associated with biotite become abundant in the groundmass, while the augite is of a much paler tint, and occurs also as phenocrysts. The felspar, too, occurs sparingly among the phenocrystic constituents. Analcite appears in more or less rounded clearings which are free from iron ores, and consist of a loose mesh of laths of orthoclase and biotite flakes, with analcite occupying the interspaces.

Certain bands are highly vesicular and decomposed. The groundmass is largely replaced by cryptocrystalline silica arranged in minute spherules, each showing a black cross between crossed Nicols. Olivine is represented by pseudomorphs, and augite by calcite. The vesicles are filled partly with calcite and partly with beautiful rosettes of chlorite.

These rocks are more closely allied to the Late Carboniferous or Permian teschenites of Ayrshire, such as that of Lugar, than to the crinanite—analcite-syenite group which is abundantly represented at Prestwick and Dundonald, a few miles to the north.

6. *Crinanite—olivine-dolerite Group, with Associated Basalts.*—The majority of the olivine-dolerites connected with Carboniferous vulcanicity have a decided alkaline cast, which is shown by the purple colour of the augite, and by the presence in interspaces of small quantities of alkali-felspar, radial zeolites, or more often analcite. When the latter mineral is conspicuous the type becomes *crinanite*, which was first described by Flett from occurrences believed to be of Tertiary age in the Crinan district of Argyllshire (J. S. Flett (1), 1911, pp. 116-8). A connected series may be traced from olivine-dolerites devoid of alkali-felspar or analcite, and whose only trace of alkalic affinities is the presence of purple titanaugite, to rocks which contain a notable amount of analcite or radial zeolites (crinanite).

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The migration of green decomposition products of olivine and augite into the interspaces frequently obscures and renders uncertain the identification of their primary infilling. The differences between these rocks and teschenites have been indicated in a former paper (Tyrrell, 1913, p. 307). The differentiation of crinanite in the direction of melanocratism gives rise to the type known as kylite. Another mode of differentiation in the direction of an increase in the relative amounts of alkali-felspar and analcite, perhaps complementary to the above-mentioned mode, results in the formation of analcite-syenite and related types. Crinanites and associated olivine-dolerites are common both in the Carboniferous-Permian, and in the Tertiary igneous suites of the West of Scotland, but analcite-syenites and kylites are at present known only in the former petrographical period.

Many of the dykes and the sill of the shore between Doonfoot and the Heads of Ayr belong to the olivine-dolerite—crinanite group. The only rock which can be definitely identified as crinanite is the N.W. dyke in Bracken Bay. A specimen from the central part of this dyke has a medium-grained texture, and consists of broad zonal laths of labradorite (An_{60}), becoming andesine-oligoclase in narrow marginal zones, in ophitic relations with a deeply coloured brown-purple titanaugite. Skeletal ilmenite and partially serpentinised olivine are abundant. Polygonal interspaces between the felspar laths are filled with fresh analcite, but are more often obscured by the migration of green decomposition products. The rock of the Deil's Dyke near Greenan Castle is certainly of the same character. It corresponds in every detail with the Bracken Bay Dyke, with the exception that analcite cannot be positively identified in the interspaces, which are filled with green alteration products and calcite.

A Rosiwal measurement of the olivine-dolerite of the Deil's Dyke gave the following volume proportions for the constituent minerals:—

Labradorite (An_{60}),	67·1
Titanaugite,	14·7
Olivine and serpentine,	12·0
Magnetite,	3·3
Interstitial substances (chlorite, calcite, &c.),	2·9

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Assuming that serpentine has replaced olivine volume for volume and not molecularly (W. Lindgren, 1918, pp. 544, 547), an assumption that is justified by the absence of any signs of increase of volume in and around the olivine crystals, it may be argued that 12 per cent. of the volume of the original unaltered rock was occupied by olivine. Similarly it is probable that the 2·9 per cent. of space now occupied by interstitial products was originally occupied by analcite, or analcite and an alkali-felspar. Making these assumptions, it is possible to calculate the gravimetric composition of the original fresh rock as follows:—

Labradorite (An_{60}), - - - - - -	61·4
Titanaugite, - - - - - - - -	17·0
Olivine, - - - - - - - - -	13·8
Magnetite, - - - - - - - -	5·6
Analcite, - - - - - - - -	2·2

The titanaugite agrees generally with the pyroxene described and analysed by Dr. A. Scott from the porphyritic essexite of Crawfordjohn, Lanarkshire (A. Scott, 1915, p. 459). Judging from the bright colours of the serpentine resulting from its alteration the olivine is probably a comparatively ferriferous variety. For the calculation of the approximate chemical composition of the original fresh rock it is assumed that the titanaugite has the same composition as the Crawfordjohn mineral, and that the olivine is identical in chemical composition with that of the essexite of Montarville, Quebec (Iddings, 1911, p. 380). The iron ore is strongly magnetic, as shown by testing the rock powder with a bar magnet. Hence it is probably pure magnetite, although it may possibly contain a little titanium. It is dealt with in the calculation as pure magnetite. The analysis of the rock, calculated upon the above assumptions, is given in the Table (I.) below—

	I.	II.	III.
SiO_2, - - -	46·3	43·94	44·21
TiO_2, - - -	·8	2·45	2·58
Al_2O_3, - - -	20·1	14·03	16·38
Fe_2O_3, - - -	4·6	1·95	5·26
FeO, - - -	6·5	11·65	7·80
MnO, - - -	—	·32	·21

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	I.	II.	III.
MgO, - -	7·3	10·46	6·78
CaO, - - -	10·1	8·99	8·65
Na_2O, - - -	3·7	2·68	2·97
K_2O, - - -	·1	·33	·47
H_2O+, - -	·2	2·31	1·77
H_2O-,		·85	2·35
P_2O_5, - - -	·1	·20	·32
Rest, - - -	—	·26	·45
	99·8	100·42	100·20

I. Olivine-dolerite (*cf.* crinanite), Deil's Dyke, Greenan.

II. Crinanite, Slac nan Sgarbh, 1 mile N. of Inver Cottage, Jura (Mem. Geol. Surv., Geol. of Knapdale, Jura, and N. Kintyre, 1911, p. 118).

III. Crinanite, 5-foot dyke, N. of Mermaid's Hole, Lundy Is. (Summ. Prog. Geol. Surv., for 1915, 1916, pp. 23-4).

A comparison of this analysis with that of the type crinanite from Jura (II.) shows that the rock of the Deil's Dyke is more felspathic and less olivinic than the type. It is also less rich in analcite, and its iron ore is magnetite, whereas that of the type rock is clearly ilmenite. The analysis of a crinanite dyke from Lundy Is. (III.), recently published by the Geological Survey, is very close to that of the Deil's Dyke.

The olivine-dolerites of this group may be divided into two sub-varieties, of which the first may be represented by the beautifully fresh rock forming the interior member of the N.W. multiple dyke cutting the agglomerate of the Heads of Ayr. This rock shows rods and laths of labradorite in ophitic relations with small plates of purplish augite which are cut up by the enclosed felspars into numerous small, apparently disconnected, polygonal strips. Perfectly fresh olivine is abundant in small interstitial grains, along with a subordinate quantity of magnetite. Rocks of this character, but of a lesser degree of freshness, are found in the marginal member of the above-mentioned multiple dyke, and in the little 3-foot N.W. dyke between Craig Tara and the Deil's Dyke.

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The other variation is seen in the small sill of Langhill Point. In thin section this rock is seen to consist of tabular porphyritic felspars (basic labradorite, An_{63}), which are, however, connected by crystals of intermediate sizes with the felspars of the groundmass, and pseudomorphs of porphyritic olivine, in a groundmass consisting mainly of felspar laths (An_{50}) not much inferior in size to the porphyritic generation, with subordinate granular augite and magnetite. The olivines are completely replaced by carbonates, and the alteration has been accompanied by the development of a considerable amount of magnetite disposed in the form of a network which doubtless represents the irregular fissures of the original mineral. The magnetite is now in process of alteration to hæmatite, as is shown by the appearance of a rosy stain in places on the grey metallic surface of the mineral as viewed by reflected light.

7. *Tholeiite* (*Brunton Type*).—The only example of this type is the 13-foot N.W. dyke at Craig Tara. The rock is rather variable, but the dominant variety is a typical tholeiite of Brunton type (Tyrrell, 1917, pp. 350-2). It shows numerous small laths of acid labradorite (An_{50}) with equidimensional grains of yellow augite, and a small amount of serpentinised olivine, in an abundant base of dark glass showing the beginnings of devitrification, and carrying numerous rod-like and reticulated black microlites. In the comparative abundance of small grains of olivine the rock shows a transition towards the olivine-tholeiite of Corrie type (*ibid.*, p. 352).

General Conclusions.

Structure and Age of the Agglomerate Masses.—The volcanic outbreak which gave rise to the Heads of Ayr agglomerate began early in the Cementstone period (Lower Carboniferous), as shown by the conformable stratification of the agglomerate upon the sediments at the western edge of the vent. Sir A. Geikie noticed this interstratification, and assigned the vent to the puy type of eruption, which, while generally of the age of the Carboniferous Limestone Series, may sometimes be earlier, as in the present case (Sir A. Geikie, 1897, pp. 416, 436). The episode probably took place in two stages, as shown by the appearance of sediments upon the foreshore opposite the central recess between the two main masses of agglomerate. The

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ground plan of the Heads (see Fig. 1) at once suggests a double vent, the two roughly cylindrical masses of agglomerate coalescing along the line of the recess. The western mass was the earlier, as its materials are interstratified with a low horizon in the Cementstone Series; whereas the agglomerate of the eastern mass is clearly interstratified on its eastern edge with strata of the same series but upon a higher horizon.

The western edge of the multiple vent is characterised by beds of fine agglomerate and tuff which have a practically vertical attitude. The high dip is maintained for a hundred yards or so inwards, but towards the centre of the vent the material becomes unstratified, and its attitude there cannot therefore be ascertained. The high dip may be due to faulting at the margin of the vent, or it may be due to the collapse of stratified agglomerate and tuff owing to the ebbing of a lava column in the vent, leaving the mass unsupported below. It is clear, however, as shown later, that no lava reached the surface during this volcanic episode. It was suggested during the discussion upon this paper that the development of the second stage of activity at the eastern side of the vent may have been the cause of the withdrawal of support upon the western side, and the consequent collapse of the western falls of the crater.

The filling of the vent is of three kinds—fragments and blocks of Lower Old Red Sandstone lavas, rounded cobbles of weathered lherzolite, and fragments of adjacent sediments. During repeated visits to the Heads not a trace of the distinctive Carboniferous igneous material was found, although closely sought. Hence it is clear that the Heads of Ayr vent was purely explosive. It drilled its way through the subjacent Lower Old Red Sandstone lavas and the overlying cementstones, but never achieved actual eruption of molten material at the surface. By the accident of its location it is a Lower Carboniferous vent largely filled with Old Red Sandstone igneous material. The latter, of course, has no genetic connection with the vent, but is merely the country rock through which the vent was drilled.

The abundant fragments of lherzolite in the vent present a different problem. Daly has called volcanic explosion without extrusion of molten material *phreatic explosion* (Daly, 1914, p. 282), and ascribes it to the heating of phreatic waters (Suess's

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term for circulating waters not of magmatic origin) by a subjacent intrusion. If a similar origin be ascribed to the Heads of Ayr vent, then the lherzolite may represent fragments of this intrusion. Daly has further called attention to the association of small tuff vents, such as those of Fifeshire and Ayrshire, with small intrusive masses (*ibid.*, pp. 297-8).

Fragments of ultrabasic rocks have now been found in many vents and intrusions of the Carboniferous-Permian igneous period in the Midland Valley of Scotland. In one case from South Bute, described by Dr. W. R. Smellie (1915, pp. 351-3), the ultrabasic fragments are enclosed within a small intrusion of amygdaloidal olivine-basalt. The xenoliths average 4 to 6 inches in diameter, and consist mostly of very fresh types of gabbro, anorthoclase, dunite, various pyroxenites and augite-peridotites, and serpentine, with which are associated fragments of basalts of Hillhouse and Dalmeny types, and large fresh pieces of augite. In the vent of the Black Rock, on the Ayrshire shore south of Fairlie, occur numerous fragments of augite (J. Young, 1894, pp. 13-5), which have apparently come from a limburgite lava. Dr. Smellie also found a coarse biotite-pyroxenite in this vent (1915, p. 352). In 1908 I described a dyke of olivine basalt crowded with xenoliths of sandstone, shale, and "ophicalcite," which cuts the lower part of the Carboniferous Limestone Series in the Caledonian Railway cutting to the south of Barrhead, Renfrewshire (Tyrrell, 1908, pp. 195-201). The "ophicalcite," which I then regarded as fragments of the Cowglen Limestone metamorphosed by the dyke, is really a carbonated peridotite, consisting mainly of a granular mosaic of calcite and secondary cryptocrystalline silica, with a good deal of residual brown and green serpentine, and small fragments of a brown chrome-spinel. The brown serpentine appears to be pseudomorphous after a pyroxene. The rock closely resembles the lherzolite of the Heads of Ayr, but thorough carbonation has much more completely destroyed the evidence as to the original minerals.

In East Lothian a series of very basic sills, analcite-basalts and monchiquites, similar in many respects to the lavas of the Carboniferous Limestone Series in the Bathgate Hills, cut the strata of the Carboniferous Limestone Series, and are believed by the Geological Survey to represent the last stage of activity

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of the Lower Carboniferous igneous episode in this district (E. B. Bailey, 1910, pp. 99-101, 105-13). These rocks, however, are identical with some occurring within the Permian volcanic vents of Fifeshire and Ayrshire, and are associated with teschenites which, in the West of Scotland at least, are almost certainly of Late Carboniferous or Permian age. The interest of these rocks, however, in connection with the present topic, is that they often carry olivine nodules or other xenoliths of ultrabasic rocks (E. B. Bailey, pp. 107-9). Dr. J. D. Falconer (1906, p. 134) has described similar inclusions in the basaltic lavas of the Carboniferous Limestone Series of the Bathgate Hills. The Permian vents of Fifeshire and Ayrshire and their associated basalts and monchiquites, often enclose ultrabasic xenoliths, also xenocrysts of olivine, augite, hornblende, biotite, and anorthoclase (Sir A. Geikie, 1902, p. 205). In Ayrshire the vents of Patna Hill, Carskeoch, Keir's Hill, and others, carry detached crystals of augite, biotite, and alkali-felspars; and these, as well as xenoliths of ultrabasic rocks, also appear enclosed in the monchiquites of Carskeoch and Keir's Hill (Tyrrell, 1912, p. 78). G. V. Wilson has described xenocrysts of augite, hornblende, and biotite in the basic group of vents near West Kilbride, in North Ayrshire (1916, p. 93). Numerous lherzolite nodules have been found in a recently discovered intrusion of nepheline-basalt within a Permian volcanic vent at Ashentree Glen, 3 miles N.E. of Patna, Ayrshire.

These ultrabasic xenoliths are then widely distributed, both in space and time, through the Scottish Carboniferous-Permian igneous rocks, and point to extensive intrusion of ultrabasic materials at the roots of the ancient volcanoes. None of these intrusions, however, as far as is yet known, have been exposed by erosion; but it is possible that they might be located by magnetic survey, as has been done in the similar case of the hidden intrusions beneath the numerous phreatic vents of Franconia and Suabia (Daly, 1914, pp. 283-4).

The *Greenan agglomerate*, in the exposed sections, clearly forms a large pod or lenticle interstratified with the cement-stones, but on a higher horizon, and therefore of a later date than that of the Heads of Ayr. The vent from which this material was derived is nowhere visible. It may be to seaward of the present exposures of agglomerate, or it may be concealed

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in the ground about Greenan Farm. The chief constituents of the Greenan agglomerate are fragments of mugearite and subordinate cementstone sediments. Hence the filling of the vent is of a distinctively Carboniferous type, and it may be surmised that the episode proceeded to the point of eruption at the surface, giving rise to one or more mugearite lavas, which, however, are not seen anywhere in the vicinity, but may be to seaward of Greenan.

Age and Relations of the Small Intrusive Masses.—The small bosses and dykes of analcite-nepheline-basalt intrusive into the sediments and agglomerate of the Heads of Ayr, and the teschenite dykes of the Long Rae which may be petrographically associated with them, present a puzzling problem as regards their age. They are identical with rock types which, in the West of Scotland, are of Late Carboniferous and Permian ages. The analcite-nepheline-basalts particularly occur in the small vents of Permian age in Ayrshire, and also in Fife. Furthermore, a xenolith has been found in one of the bosses (see page 349), a fragment of lherzolite, fresher, but mineralogically identical with the lherzolite boulders of the agglomerate. The question arises, therefore, as to whether these bosses are, or are not, of the same period of eruption as the agglomerate of the vent. Three possibilities are presented—the vent and intrusions may both be of Cementstone age; the agglomerate may be of Cementstone age and the intrusions of Permian age, representing a Permian volcanic episode occurring along the same channel as the earlier one; or the vent and intrusions may both be of Permian age. The last-named alternative is decisively negatived by the evidence of interstratification of the agglomerate with the cementstone sediments, and by the nature of the filling. The true Permian vents are almost invariably characterised by the presence of red-speckled fragments of the ultramafic olivine-basalts, analcite- and nepheline-basalts, of the Permian volcanic episode. The only way in which this hypothesis can be maintained for the Heads of Ayr section is by supposing the interbedded material to represent a cementstone volcanic episode, and the material filling the main central vent to be of Permian age. Facts which might be thought to support this hypothesis are the presence of lherzolite fragments in the central parts of the vent, and not in the interstratified

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portion; and the great disturbances, resulting in agglomerate with a vertical attitude, at the western margin of the vent. The nature of the filling, however, as indicated above, makes this view highly improbable. As regards the first view, I know of no occurrence of analcite-nepheline-basalt in a vent of unquestionable Calciferous Sandstone age, or in association with the igneous products of that period of vulcanicity. Hence the balance of evidence, such as it is, rests with the second hypothesis, that the agglomerate is of Cementstone age, but that the intrusions belong to a later date, and represent a slight reawakening of the focus during the Permian volcanic episode.

The crinanites and related olivine-dolerites of the stretch of coast dealt with in this paper belong to a suite, well represented along the shores of the Firth of Clyde, which is believed to be of Tertiary age. These rocks have been referred to in two previous publications, in which the evidence as to their age is discussed (Tyrrell, 1913, pp. 307-9; 1917, pp. 353-5). The dykes intrude rocks of ages ranging from the Lewisian of Lewis (Stevens, 1913, pp. 38-9), the Dalradian of the western and south-western Highlands, to the Tertiary lavas of Mull and Skye (Flett, J. S. (2), 1911, p. 41). In a visit to western Skye in 1913 I found a crinanite dyke cutting basalt lavas near Idrigil Point, west of Uig. The lavas themselves at this point are rich in interstitial zeolites, as has also been recorded for the lavas of other parts of Skye (Harker, 1912, p. 378). This raises the point as to whether the crinanite dykes are the hypabyssal representatives of the magma that gave rise to the prevalent types of the Tertiary plateau basalts. The similarity of the chemical analyses of the rocks is well brought out by comparing the symbols of the analyses in the American Quantitative Classification—

Olivine-basalt lava, Drynoch, Skye, -	III.5	4.4(5)	Auvergnase
Olivine-basalt lava, Orval, Rum, -	III.5	(3)4.4(5)	,,
Crinanite, Inver, Jura, - - -	III.5	(3)4.5.	,,

The question of the age of the crinanite—olivine-dolerite dykes is complicated by the fact that similar rocks also occur in unquestionable connection with the Carboniferous-Permian igneous suite of the West of Scotland (Tyrrell, 1912, p. 120); and Dr.

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Harker, upon a balance of evidence, has assigned the dyke occurrences outside the Tertiary basaltic plateaus (in Argyllshire and elsewhere) to the Permian volcanic episode (Harker, 1917, pp. 83, 95). But the geographic distribution of the whole set, their general N.W. trend, coupled with the fact that the dykes occur in Arran cutting Triassic sediments, and in Skye and Mull, cutting the tertiary basalts, seem rather to indicate their connection with Tertiary volcanic activity. Their mode of occurrence as dykes is also in favour of their Tertiary age, as dykes are very rare in connection with the Permian volcanic episode.

In concluding this study I have to acknowledge the kind assistance given me by Mr. R. Macmillan, M.A., B.Sc., science master at Ayr Academy, by his company in the field, and by the hospitality that he has extended to me upon all occasions.

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No. XIX.—On Carboniferous Crinoids from Fife: With Notes on Some Localities, and Provisional Lists of Species. By James Wright.

Introduction.

Viewing a section of one of the Lower Carboniferous Limestones, and noting the prodigious numbers of crinoid fragments of which it is usually composed, one cannot but regret that so very few complete specimens of the organisms have been preserved to us. This has always been a subject of lament to Scottish palæontologists. In the Carboniferous Limestones of Scotland, as a whole, cups even appear to be of rare occurrence, and judging from the lists of species hitherto published, and the specimens exhibited in our museums, they occur at widely-separated localities. Now, in Fife this is not the case, where, I am glad to say, it has been my good fortune to find several localities within a short distance of one another, where large numbers of cups and more or less entire specimens may be found. This is an interesting fact, for among the many classes of organisms which abound in our rocks there is, I think, no more beautiful object than a well-preserved crinoid—a specimen which always brings a thrill of joy and delight to the heart of its discoverer.

If we examine the collections of Scottish Carboniferous fossils which are exhibited in our museums, the crinoids occupy but a small space compared with other classes. Further, if we note the lists of crinoid species from Scotland recorded in various publications, the total is by no means large. Scottish Carboniferous crinoid nomenclature is in a very unsatisfactory state at present, and when we remember that many of the species given in these lists are probably founded on stem or arm fragments only, the paucity of well-preserved and determinable specimens is still further brought home to us.* For example, one often sees the

* See lists in Geol. Survey Memoirs, etc.

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1. 2.

Hydreionocrinus. No. 3 Bed, Invertiel.

J. Wright Colln., No. 2107. 2/3 Natural size. Two views of the same specimen.

1.—Posterior view. 2.—Anterior view.

J. Wright, Photo.

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name "*Platycrinus trigintidactylus*," given to certain arm fragments. Now, from my experience, I have reason to believe that these arms do not belong to *Platycrinus* at all, but to an undescribed species of *Hydreionocrinus*,[16] whose arm fragments appear to be fairly common all over Scotland in the limestone and shales of the horizon hitherto known as the "Hurlet." (See Plate XIII.). More or less complete examples of the species are often found in Fife.[19] Again, the name *Actinocrinus* is often given to plates and spines—clearly of crinoidal nature—which are now known to belong to the ventral sac of *Hydreionocrinus*.[16] In these instances alone we have two genera recorded when there should only be one. We see, then, that meagre as the recorded crinoid fauna is, it is impossible to get from these lists any clear idea of its character and distribution in our Scottish Carboniferous rocks. This will only be obtained when Dr. Bather works out the Carboniferous forms and revises the whole system of nomenclature. In the meantime the worker among crinoids must do the best he can, but it will be understood the work is far from easy when it is mentioned that, in addition to the difficulties already stated, literature on the crinoidea generally is very difficult to procure in Scotland. Whether this is due to the lack of well-preserved specimens having caused a want of enthusiasm on the subject, I know not. As a private individual, however, with limited opportunities, the fact remains that any of our libraries to which I have had access are woefully deficient in works pertaining to this particular class of organisms.

Having regard to these circumstances, the subject of this paper is not one which I should care to undertake at the present time. Under the prevailing uncertainty of conditions, however, it seems desirable even at this stage to place on record some additional facts regarding the Fife crinoids, which I have collected during the last 18 years, together with a few provisional lists of species. These lists can only be fragmentary at the best, since several of the Fife crinoids belong to undescribed species, and generic names in most cases can only meantime be given to the specimens. To several of the specimens I cannot even give generic names, as it has been impossible for me to submit all the material to Dr. Bather. These, therefore, do not find a place in the accompanying lists at all, and can only be added when the

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fauna is properly worked out. In the nature of the case then, these lists must suffer from defects similar to those already mentioned. They have this advantage, however, the species are *all* named from cups or crowns; the names are in the majority of cases given on the authority of Dr. Bather or Dr. Springer; and all the specimens may be seen and examined in my collection. Many of the genera herein named may also be seen in the collection of Mr. Robert Dunlop, now in the Museum of the Carnegie Trust, Dunfermline. I should like to take this opportunity to thank Mr. Dunlop for much kindness in connection with this paper and in various other ways.

LOCALITIES.

1. Invertiel.

As I have shown in another paper,[15] Invertiel is one of the richest—if not the richest—crinoid localities in Fife. The quarry has been long disused, and as the Town Council of Kirkcaldy used it as a toom for some years the best section of the main limestone is now covered up. The shale beds above the limestone are however still accessible, and from these shales a large crinoidal fauna has been obtained. From the palæontological point of view the most interesting feature about the section is the character and distribution of the crinoid fauna, and for convenience of description and working I have divided the shales into three beds called respectively Nos. 1, 2, and 3. These divisions are not altogether artificial, for it is found that a somewhat different crinoid facies characterises each of the beds.[15] Space will not admit of fuller details here. Suffice it to say that No. 1 Bed, about 3 ft. 6 in. thick, rests immediately above the main limestone seam. Then comes 2 ft. 6 in. of limestone, upon which lie about 20 ft. of shales, called No. 2 Bed. Above this series is a persistent band of limestone, 9 in. to 3 ft. thick, surmounted by 3 ft. to 4 ft. of shales, called No. 3 Bed. The whole of the shales are calcareous and contain a marine fauna, the distinguishing character of which is the abundance and beautiful preservation of its crinoid elements. Crinoid cups occur with more or less frequency in all the beds. As far as numbers are concerned No. 1 Bed is the most prolific. In No. 2 Bed individuals are

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comparatively rare, and in No. 3, while the same remark is applicable, the bed itself is redeemable in the eyes of the searcher for crinoids because of the occasional occurrence of beautifully-preserved crowns, and sometimes complete specimens with the stem attached. Characteristic genera in No. 1 Bed are:—*Platycrinus*, *Rhodocrinus*, *Ulocrinus*, *Mespilocrinus*, *Eupachycrinus*, *Zeacrinus*, *Amphicrinus*, *Allagecrinus*; in No. 2 Bed, *Hydreionocrinus*, *Ulocrinus*; and in No. 3 Bed, *Woodocrinus*, *Hydreionocrinus*, *Amphicrinus*, *Zeacrinus*, *Onychocrinus*.

Taking the crinoid fauna of Invertiel as a whole, the great majority of the species represent the two great sub-classes of the Crinoidea, viz., the Monocyclica, in which there is only one circlet of basal plates in the cup, and the Dicyclica, in which there are two circlets of basal plates in the cup. In the Monocyclic sub-class *Platycrinus* may be taken as the typical representative, at Invertiel and in the Fife rocks generally, and in the Dicyclic we have several species of *Zeacrinus*, *Eupachycrinus*, *Ulocrinus*, *Hydreionocrinus*, *Woodocrinus*, *Poteriocrinus*, etc, which are very abundant at Invertiel and other localities. As individuals and species the Dicyclic types far outnumber the Monocyclic.

As given further on, the number of species in the Invertiel list totals 22. Those previously recorded are comparatively few. In fact, so far as I can find out, there are only three publications in which any specific list is given. These are noted below. Before detailing them, it may be mentioned that perhaps the first reference* to Invertiel as a crinoid locality is to be found in the "Annual Register" for the year 1760. Under the initials, "J.M.,"[1] the writer states that about a year and a half before that date, *i.e.*, in 1758, a quarry was opened "at a farm called Enderteel." He notes the shells and great number of "stalks of seaweed" (*i.e.*, crinoid stems), of which the rocks in the quarry are composed, and remarks that "the very capsulæ which contain the seed" are preserved. Possibly this last remark refers to cups. He then enters into speculations on the causes which have placed marine limestones like that of Invertiel and other localities so far above the level of the sea.

Perhaps the first published record[2] of a Fife crinoid is to be

* I owe this information to Mr. MacBean, editor of the *Fifeshire Advertiser*, who was so kind as to present me with the article.

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found in Phillip's "Geology of Yorkshire," where *Poteriocrinus granulosus* is recorded from "Kirkcaldy"; figures are also given on Plate IV., Figs. 2, 4, 8, 9, and 10.

The first undoubted list of crinoid species appears in Leighton's "History of Fife,"[3] published in 1840. In the chapter on the geology of the county by Rev. Mr. Anderson of Newburgh is a list of eight species, viz., *Cyathocrinites planus*, *C. tuberculatus*, *C. rugosus*, *C. quinquangularis*, *Platycrinites lævis*, *P. rugosus*, *Poteriocrinites tenuis*, *Rhodocrinites verus*.

These eight species are founded on the nomenclature and work of J. S. Miller (Nat. History of the Crinoidea, Bristol, 1821), but they are bracketed together from Invertiel and Cults, so that it is not clear which of the species are characteristic of Invertiel, or whether it is meant that all the species belong to both localities. It is also impossible to tell how many of the species were named from stem fragments or cups, as Mr. Anderson's collection seems to have been lost sight of. In 1876 Mr. Arthur Pratt[8] gave a very interesting account of two visits which he made to Invertiel during the course of that year, and remarks on the abundance of crinoid heads or cups, of which he collected "five or six various species" . . . . "and stems or arms of about a dozen different species." At the end of his paper he gives a list of the species he had been able to identify as follows:—*Poteriocrinus nuciformis*, M'Coy; *P. calyx*, M'Coy; *P. Maccoyanus*, De Kon; *P. crassus*, Miller; *Cyathocrinus planus*, Miller; *Platycrinus* species.

In 1900 appeared the Geological Survey Memoir[13] on "Central and Western Fife and Kinross," and in the fossil list from Invertiel are given three species of crinoidea, *Hydreionocrinus sp.; Platycrinus sp.; Poteriocrinus crassus*, Miller; and the Blastoid *Astrocrinites Benniei*, R. Eth. Jun.

In 1911 in the paper[15] already referred to I gave an account of the character and distribution of the crinoids at Invertiel, and in 1912[19] some notes on, and a few illustrations of the Carboniferus crinoid fauna of Fife, more particularly with reference to the species which I had found at Invertiel and in the so-called "Hurlet" limestone at other places in the county. No attempt was, however, made to give lists of species. The present notes are intended to place in tabular form all the species known

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to me at that time, with some additional species collected since then. Some notes on the species will also be found at page 20, and numbers are given for comparison with individual specimens or drawings.

2. Seafield Tower.

The limestone at Seafield Tower is, as I have always contended, the shoreward prolongation of the Invertiel bed. At the base is a black shale a few feet thick, crowded with fossils, among which are found cups of *Ulocrinus globularis*. This bed is not seen at Invertiel. Above comes the thick limestone—the main seam of Invertiel—and above it we find the No. 1 Bed of Invertiel, containing the same crinoid fauna in a similar state of preservation. Nos. 2 and 3 Beds are also found here divided by their thin limestone bands with the fauna, so far as yet made out, again similar to the Invertiel beds. It may be remarked, however, that a flat-lying shore section of this kind is much more difficult to work than an inland one, so that much remains to be done here. The species so far discovered will be found in the list.

3. Shales and Limestone above Seafield Tower Limestone.

None of the limestone and shales overlying the Seafield Tower limestone is to be compared with it for abundance and preservation of crinoid remains. As a matter of fact, the list of crinoid species which I am able to give from these beds is very scant indeed. In the group of shales and cement stones, believed by Mr. Macnair to be the equivalent of the Calderwood cement of the West of Scotland, immediately overlying the Seafield Tower sandstone[23] three species of cups are all that so far have occurred to me. One of them is the very rare and remarkable genus *Tribrachiocrinus** now recorded for the first time in this hemisphere. The genus was only previously recorded from Australia. The *Cromyocrinus*† which occurs here appears similar to the type of Seafield Tower and Invertiel. The same remark applies to *Ulocrinus*. The only other bed which has so far yielded

* Dr. Bather has determined these specimens, and informs me in a letter that he is studying them and hopes to describe them shortly. (Jan., 1918).

† Perhaps this cup will turn out to be a *Hydreionocrinus*; see page 383 of this paper, under "*Hydreionocrinus*."

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a recognisable crinoid is the shale overlying the faulted "*cauda galli*" limestone, about 100 feet higher in the shore section. From this bed I have obtained a *Woodocrinus* crown in a fair state of preservation.

4. Potmetal, Bogie, and Chapel.

For our purpose these localities may be grouped together. At Potmetal is a band of shales which has been caught up and much altered and hardened by a dolerite intrusion. The shales presumably overlie the horizon of the Bogie and Chapel limestones, and are apparently on the same position as the No. 3 Bed of Invertiel, for the crinoids so far found consist mostly of crowns of similar species to those occurring in the latter bed. These are the only two beds in the district, so far found, which contain crinoids in any number, in this state of preservation. The limestone beds of Bogie and Chapel are extremely crinoidal, but the determinable fauna is rather poor.

5. Roscobie.

Roscobie is situated about four miles north of Dunfermline, and has long been known as an excellent locality for fossils of various classes. While the crinoids, as individuals, are not so abundant as at Invertiel, the striking feature is their rare beauty and fine state of preservation.[19, 16] (See Plates XIV. and XV.). In the Geological Survey Memoir five species of crinoids are reported from Roscobie, viz., *Cupressocrinus impressus*, M'Coy (*Poteriocrinus Maccoyanus*, de Kon. and le Hon.); *Hydreionocrinus globularis*, de Kon.; *Platycrinus* near *arenosus*; *Platycrinus trigintidactylus*, Aust. and *Poteriocrinus crassus*, Miller. The present list numbers 19 species, and there will be others to add when the collection is worked out.

Apart from its crinoids and other fossils the Roscobie section shows features which, from the point of view of structure and formation, are not to be seen elsewhere in Fife. A few additional unpublished notes on the subject may therefore be of interest The general succession of the strata as shown in the quarry (1912) consists of—

Drift, - - -	- Irregular thickness.
Sandstone, -	- 12 ft.

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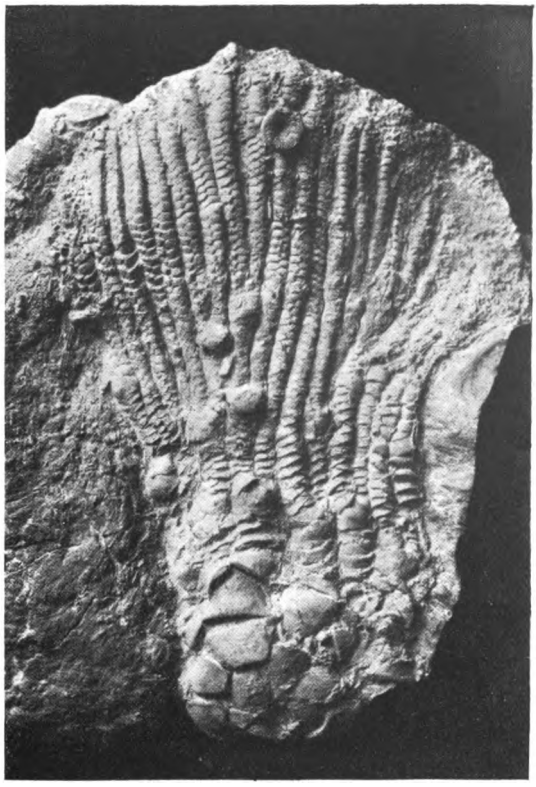

Hydreionocrinus, Roscobie. 2/3 Natural size.

J. Wright Colln., No. 1675.

R. Milliken, Photo.

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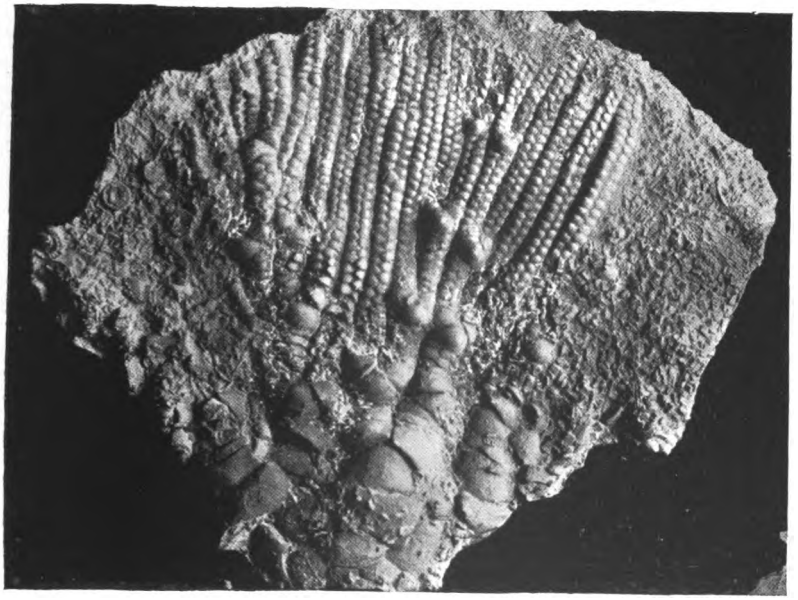

1.—*Hydreionocrinus*, Roscobie. J. W. Colln., No. 1674.

2.—*Synerocrinus*, Roscobie. J. W. Colln. No. 2118.

3.—*Poteriocrinus?* near *P. plicatus*, Roscobie. J. W. Colln., No. 1670.

All figures natural size.

J. Wright, Photos.

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Black shales (highly crinoidal in lower portion), - - -	40 ft.
Limestone, - - - -	40 ft.

The character of the beds is best seen at the north-west corner of the quarry where the strata dip to the east at 10 degrees. The limestone consists of a well-bedded rock divided by partings of more shaly material. At the base is a strong blue limestone, 6 feet thick, with *Productus giganteus* as a characteristic fossil. Above it, separated by a thin layer of shale, lies a darker bed, 2 ft. 6 in. thick, full of *Lithostrotion junceum.* This bed is surmounted by another blue limestone, 3 feet thick, full of patches of chert, and with a very irregular upper surface. It is overlaid in turn by limestone beds, grey in colour, some of which weather yellow, and full of large crinoid stems, brachiopods, and other fossils. These beds, divided by partings of shale, continue to the top of the section. The group of shales, 40 feet thick, which overlie the limestone contain in their lower portion, where they are calcareous, thin limestone bands, and higher up bands and nodules of ironstone. The shales become less calcareous as they are traced upwards, and gradually merge into the overlying sandstone, which is best seen on the eastern face of the quarry. The beds here described do not differ very markedly from any of the limestones occupying the same stratagraphical position in Fife. Indeed, some of their characters remind one of the limestones o Bogie and Chapel, near Kirkcaldy, but they gradually undergo a change. For about 50 yards at this point the beds retain their easterly dip, after which they become horizontal for a short distance. The upper grey beds are then seen to rise in an opposite direction to that of the dip, and abut against a mass of pale *grey* or *white* limestone, which has more or less lost its bedded character, and which is wedged in between them and the *blue* limestone beds of the bottom of the section. The upper grey beds are again tilted over, this time in the direction of the dip, and the effect is that we have in section an irregular mass of limestone, the upper part of which forms a dome-shaped protuberance, which rises 15 to 20 feet above the general level of the ordinary beds. The lowest blue limestone continues under this mass in the direction of the dip, and the whole of the limestone

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here attains a thickness of 60 feet. The feature is perhaps best explained by looking along the line of strike which has been followed in quarrying operations. It it there seen that the limestone has been thrown up into a great fold, the axis of which runs in a north and south direction. The limestone, however, has not only been folded, but the upper part seems to have been pressed or ridged up into a series of irregular bosses for a distance of at least 250 yards. Altogether the remains of seven of these are visible along the face of the quarry. Unfortunately, no exact record has been kept of their dimensions, but when the shales were taken off these bosses, or humps as they are termed by the quarrymen, formed in reality a group of dome-shaped eminences along the ridge of the fold. How to account for these masses seems difficult. Probably earth movement, lateral pressure and faulting have had their effects. At any rate, beneath the "humps" and along the whole line of strike, the limestone is found to be slickensided, crushed in some places, and altered into a massive pale grey or white bed with a great development of free *calcite* and a smaller proportion of other minerals. On the top of the last hump exposed (1912) aggregations of iron pyrites were conspicuous. On the whole, this alteration in the limestone has had little effect on the majority of the fossils, most of which are beautifully preserved. A noticeable feature is that shells of *Productus* and other brachiopods have their interiors filled with crystals of *Calcite*, among which may sometimes be seen lovely hair-like crystals of *Millerite*. The alteration of the rock is, as indicated, continuous along the line of strike, but so far as can be ascertained the beds regain their ordinary characters towards the dip side (*i.e.*, judging from the evidence shown in the mine and from information given by the quarrymen). The peculiarity, however, is that it is the upper grey beds which seem to have undergone most alteration, for the lowest *blue* limestone beds are found to continue underneath the white material. The only difference that can be noted is perhaps a slight thickening and a folding or bending which coincides with the contours of the humps. From all the information I have been able to obtain, the area occupied by the altered white limestone will extend horizontally (in the direction of dip) 150 feet; vertically, *i.e.*, to the apices of the humps, 50 feet, and at least 250 yards along the strike to the south.

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How far it extends to the north, beneath its covering of shales, &c., is impossible to ascertain. In his paper on the "Carboniferous Limestone Rocks of the Isle of Man,"[24] Mr. John Smith referring to the thickening of the Roscobie limestone, says—"The Roscobie instance was clearly due to a spring of water, probably furnishing a supply of lime utilised by the marine animals in building up the extra thick part, which was about 60 feet thick." A close examination does not support this theory. Mr. Smith takes no notice of the folding or faulting. If this thick altered limestone and its surface "humps" or knolls, if one may so term them, were original structures of deposition, we should naturally expect the shales to have been deposited all around, and to now run into them, instead of which they appear to follow the bending or folding of the bed. This of itself would not be absolute proof against the supposition, for the limestone may have slightly thickened in this direction; but the folding, together with the group of faults which may be seen in the limestone and in the shales on the quarry face, as well as the shattered condition of the limestone itself in some places, seem to show that some peculiar form of lateral pressure has had more effect in the thickening of the bed than may be due to any original feature of deposition. (Compare Sketch and Plates XVI. and XVII.).

Besides the slickensides which run vertically through the altered mass, others may be seen running in a horizontal direction. For example, when part of last "hump" was being quarried (1911) at a distance of 20 feet or so from the top, some dome-shaped slickensided surfaces were exposed, the contours of which coincided with the outline of the "hump" as if parts of the limestone had been moved along bodily in a horizontal direction. Besides minor faults which may be detected, a conspicuous one is seen just above the existing hump (1914), where the overlying shales are seen to have been pinched out, and letting down the sandstone of the top of the section. Another fault trending S.E. and N.W. was noticed in recent mining operations with a good deal of crushed rock between the fault planes.

Whatever may be the correct explanation of the altered white limestone, one interesting fact is, that had the Roscobie limestone been exposed on a shore line and slightly denuded we should have

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had a ridge and a series of "knolls" of pale grey or white limestone, surrounded on at least two sides by darker and more flaggy beds. Although the Roscobie limestone is much less thick than the limestone of Poolvash shore, Isle of Man, the occurrence of the altered white, in conjunction with the unaltered flaggy beds, seems to suggest that we have here an example on a smaller scale of what may be seen in the Isle of Man rocks, and possibly also in Yorkshire. Although certain differences may be detected between the Roscobie and the Isle of Man beds, there is a curious resemblance in the mode of occurrence of the fossils. For example, the fossils of the white limestone of Roscobie break out solid, and their interiors are generally filled with calcite in a

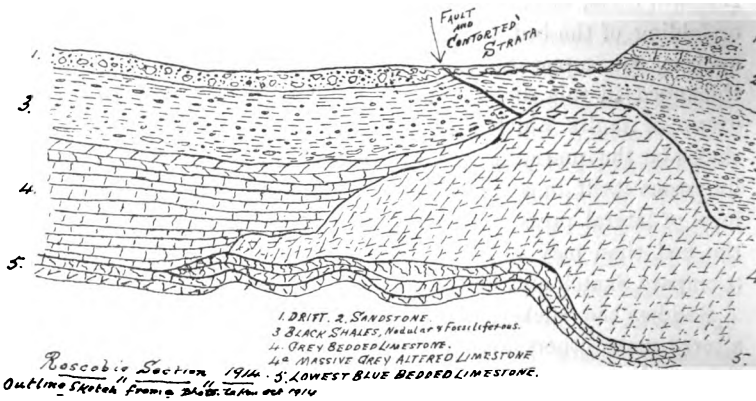

Fig. A. Roscobie Section, 1914. Outline sketch from photograph taken Oct., 1914. 1. Drift; 2. Sandstone; 3. Black Shales; 4. Grey Bedded Limestone; 4a. Massive Grey altered Limestone; 5. Lowest Blue bedded Limestone.

similar condition to the fossils in some of the ridges and knolls of Poolvash Bay. The same thing applies to the more flaggy beds where at Roscobie it is exceedingly difficult to get a good specimen, as is the case also at Poolvash.

The ridging up of the limestone into domes or "knolls" is undoubtedly a feature at Roscobie, because the movement, or series of movements, to which they owe their origin has allowed the rock to be worked very much longer than it otherwise would have been, having had the effect of lessening the thickness of the tirr. In this aspect it has contributed to the crinoid fauna, since

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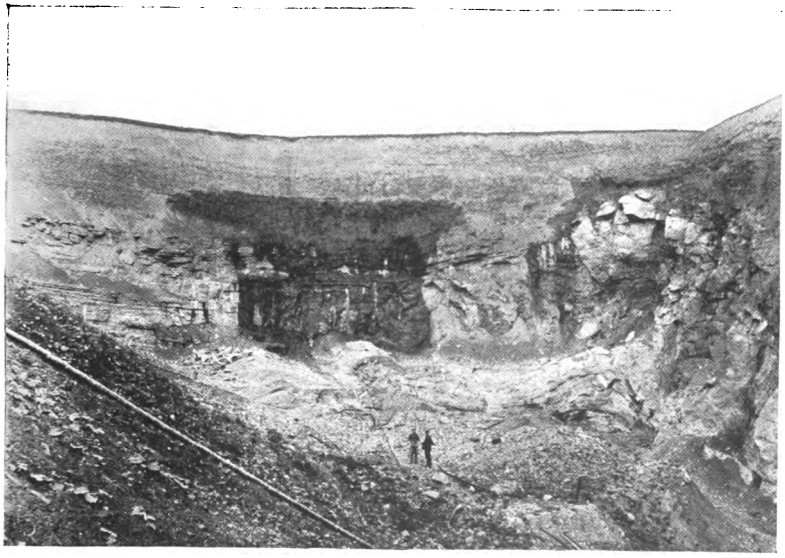
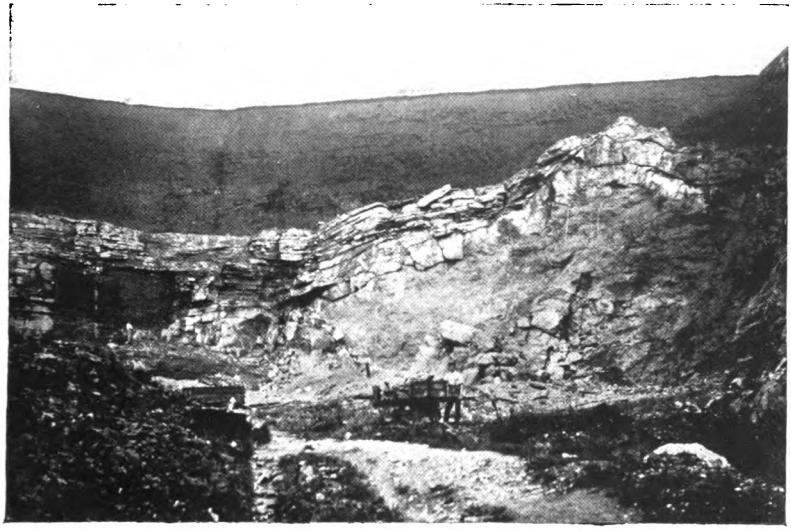


Roscobie, 1914.—Bedded and "Hump" Limestone quarried off flush with the shales, shown in lower photo.

J. Wright, Photo., 1914.



Hurlet Limestone of Roscobie, showing thickening of Limestone and "hump" or knoll.

J. Wright, Photo., 1910.

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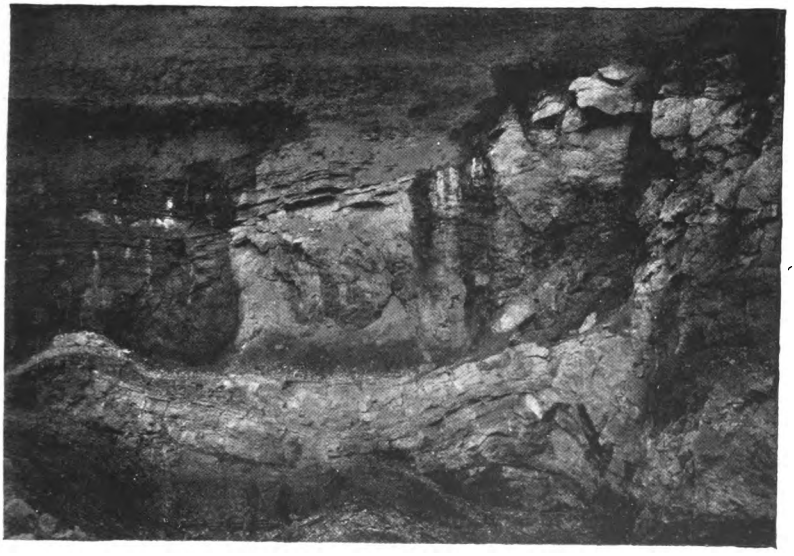

Roscobie, 1914.—"Hump" Limestone, showing bedded layers passing underneath.

J. Wright, Photo., 1914.

Hurlet Limestone of Roscobie, at point where Limestone thickens. Note downward passage of lower bedded layers which continue underneath "Hump," and the upward passage of upper layers. The altered White Limestone forms a wedge-shaped mass on the right of photo.

J. Wright, Photo., 1910.

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the species herein recorded would not have been obtained had quarrying operations ceased when the shale became too thick for removal. Had the limestone continued to dip at its normal angle, this would probably have happened many years ago.

6. Other Localities.

The other localities from which I have collected crinoids will be found in the lists. They call for little remark here until the fauna is thoroughly worked out. I am unable to give the names of all the species from these places for the reason already mentioned, viz., that it has been impossible to send all the material to Dr. Bather. This applies particularly to Ardross, which locality promises to yield a large number of characteristic forms. So far, I have found over a dozen crowns, some of them belonging to species not yet noticed elsewhere in Fife. This is notably the case with a Poteriocrinoid, whose stem cup and arm plates are ornamented with a beautiful mosaic-like pattern; and another allied species, with long arms and prominent anal tube. A *Synerocrinus* also occurs here, recorded for the first time outside of Russia.—See postscript to (19) p. 167.

Notes on the Species.

(Numbers in double brackets after each genus or species refer to typical individual specimens, or tablet of specimens, mounted and registered in the collection. These are given for sake of comparison).

Platycrinus.

((No. 1 species, 1500, 1519, 1503; No. 2 species, 1501; No. 3 species, 709.))

There seems to be at least three species of *Platycrinus* in the Fife limestones, and for want of better information I have called them Nos. 1, 2, and 3 species. Nos. 1 and 2 are particularly abundant in No. 1 Bed, Invertiel. No. 3 also occurs in the bed, but it is comparatively rare. The occurrence of the species at other localities will be noted from the lists. In No. 1 species the cup is somewhat depressed, the basals, often fused together, form only a slightly convex outline, its plates are smooth without ornamentation, and sometimes faintly grooved at the margins of the plates in adult specimens. In No. 2 species the plates are also smooth, but the basal circlet here is much more elevated, and gives the cup a somewhat stout conical aspect, distinctly different

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in this respect from No. 1 species. The differentiation of these two species, in tegminal and cup features, can only be fully worked out when a large series of specimens has been cleaned. The tegmen is often well preserved in the two species, but the larger individuals of both species are frequently crushed; in fact, very many flattened and disturbed specimens of *Platycrinus* are found in No. 1 Bed, Invertiel, which are of little use for palæontological purposes. No. 3 species is only known to me from scattered radial plates and bases. Judging from the latter, the outline of the basal circlet was similar to No. 2 species, but the cup itself bore a series of spines which radiated in the basal circlet, at any rate from the stem area to the outer margin of the plates. The spines are broken off in most specimens, the proximal ends now only being preserved, and at first sight look like lines of coarse tubercules.

Rhodocrinus.

((No. 1 species, 450x; No. 2 species, 450b; No. 3 species, 450c.))

There also appear to be three species of this genus in No. 1 Bed, Invertiel. No. 1 species with tegmen intact seems to agree with the one seen in West of Scotland collections and labelled *Rhodocrinus uniarticulatus*, de Kon. and le Hon. No. 2 species has a squat or shallow cup; its tegmen is flat, not elevated as in the previous species, and viewed from the side its outline is much compressed compared with No. 1. In No. 3 species the cup agrees in outline with No. 1 species, but the tegmen, while elevated, is also constricted. I have only one well-preserved specimen of this last species. All these are easily distinguished in uncrushed specimens. Like *Platycrinus* the vast majority of specimens of *Rhodocrinus* in No. 1 Bed, Invertiel, and other Fife localities are crushed and flattened, and it is often difficult, if not impossible, to say to which of the three species they belong. When the analyses of the cups are given and the tegminal plates worked out, this may be less difficult. The species given in the lists are determined from uncrushed specimens, and I have let them stand as Nos. 1, 2, and 3 species.

Eupachycrinus.

((No. 1 species, 419, 2098, 1504, 1012, 1013; No. 2 species, 874, 1527.))

Cups referred to this genus are very abundant at Invertiel, and

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in a less degree at other "Hurlet" localities in Fife. In general features they agree with the species of *Eupachycrinus* figured by Dr. Bather (16). In a large series, however, one notices a variation in the shape and outline of the cups, some being pronouncedly bowl-shaped and others much depressed. There is also a variation in the disposition and shape of the plates of the anal area. Generally speaking, the majority show the intercalation between the left and right posterior radials of the R.A. and anal X., as given in Dr. Bather's Fig. 13, p. 74.[16] In a few, however, the left shoulder of the R.A. abuts directly against the left posterior

Eupachycrinus.—No. 1 Sp.—*Normal Type.*

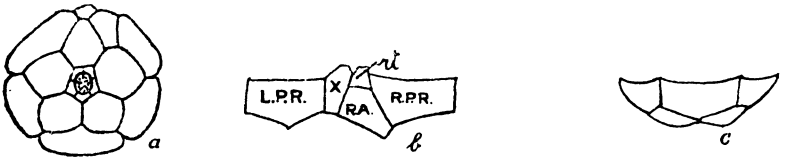

Fig. 1.

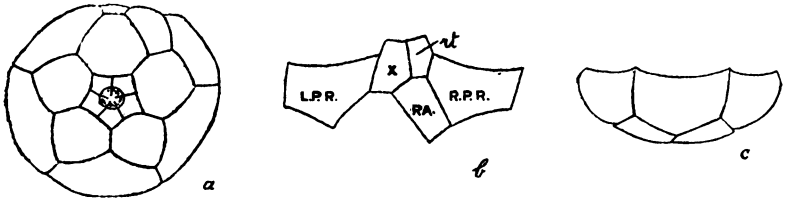

Fig. 2.

Fig. 1—J. Wright Colln. No. 2098*j*. No. 1 Bed, Invertiel × 1½.
Fig. 2— ,, ,, 1504*m*. ,, ,, × 1½.

a Cup from below ; *b* Anal area ; *c* Cup from anterior.

radial, without the interposition of the anal X. In this case the anal X. rests on the top of the R.A., as if it had been gradually forced upwards, and was in process of being squeezed out of the radial circlet.

Between these two extremes one finds a wide gradation, and in a large series of cups it may be possible to trace the passage of the anal X. upwards and outwith the limits of the radial circlet.

The great majority of the cups have smooth plates. Some,

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however, show a fine granulation on the plates, and if this is a characteristic of the species it is now in most specimens worn off. One specimen in particular (No. 1013A) shows a fine granular ornamentation on the plates. It may belong to a different species since there are fragments of arms adherent to it, which appear to differ from the portions of arms attached to cups of normal type. It may be noted, however, that among hundreds of cups of *Eupachycrinus* I have only seen three or four with fragments of arms in association, and these are very unsatisfactory as to details of structure generally. To avoid confusion until they are properly worked out, I have classed them all as No. 1 species to distinguish them from another cup of probably the same genus which I have called No. 2 species, the plates of which are ornamented with coarse tubercules or granules. It is clearly different from No. 1 species and much smaller. No. 2 species occurs at Invertiel (Nos. 2 and 3 Beds) and at Roscobie.

Since the above was written I have examined 200 cups of the common form here denominated as *Eupachycrinus*, No. 1 species. All these are from No. 1 Bed, Invertiel, with the exception of seven, which are from No. 3 Bed, Invertiel, but these latter do not call for special remark here.

Of the 200, 163 belong to what may be called the *normal type*, as represented in the drawings of specimens Nos. 2098j, 1504m, text figures 1 and 2; 37 belong to what may be called the *extreme type*, as represented by specimens Nos. 1504a, 1504i, 419i, text figures 4, 5, and 6. The variations in both types show a wide range, and it is difficult to draw a dividing line between them. As a distinction, I have classified as the *normal type* all those forms in which the R.A. is clearly separated from the left posterior radial (L.P.R.) by the anal plate; and as the *extreme type* all those in which the R.A. effects a distinct junction with the L.P.R. In the *normal type* the anal plate varies greatly in shape. At its lower end where it joins the posterior basal, it may be narrow, pointed, wedge-shaped, or triangular, just touching the posterior basal, or it may be quite broad here. In the *extreme type* the same is the case with the R.A., which, where it touches the L.P.R., may be narrow and pointed or may broaden out. The result here is that the anal plate is pushed upwards in the radial circlet.

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Eupachycrinus—No. 1 sp.

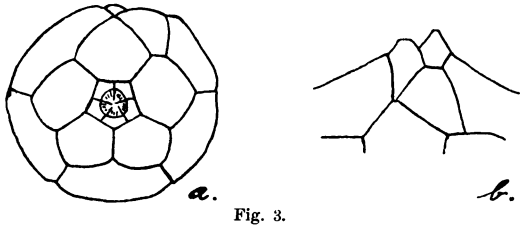

Fig. 3.

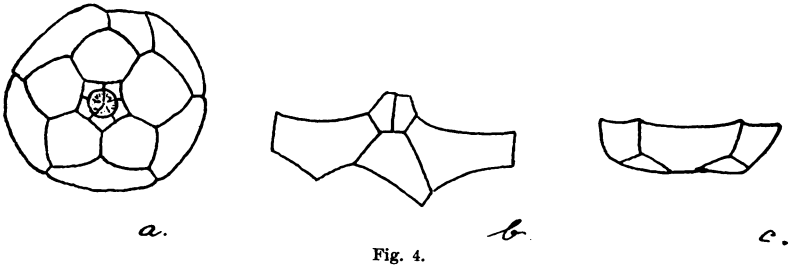

Fig. 4.

Fig. 3—J. Wright Colln. 2098*c*. *Normal Type* × $1\frac{1}{3}$.
Fig. 4— ,, ,, 1504*a*. *Extreme Type* × $1\frac{1}{3}$.
a Cup from below; *b* Anal area; *c* Cup from anterior.

Eupachycrinus—No. 1 sp.—*Extreme Type*.

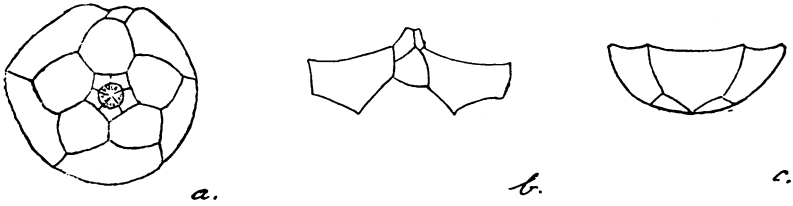

Fig. 5.

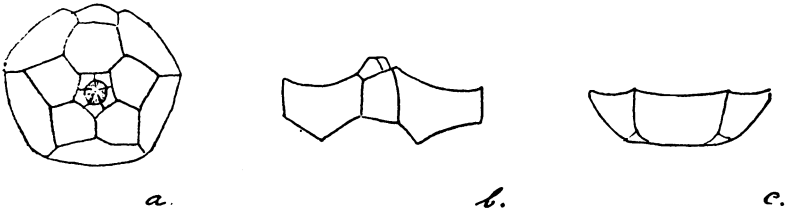

Fig. 6.

Fig. 5—J. Wright Colln. 1504 i. No. 1, Bed Invertiel × $1\frac{1}{3}$.
Fig. 6— ,, ,, 419 i. ,, ,, × $1\frac{1}{3}$.
a Cup from below; *b* Anal area; *c* Cup from anterior.

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Zeacrinus.

((81, 1665, 428, 1662, 414, 415.))

Dr. Bather[16] has described some of the Fife cups belonging to this genus. *Zeacrinus Konincki* is the name he has given to the cups, but so far as I know the arm structure has not yet been defined. From Invertiel (No. 3 Bed) and Roscobie I have a large series of crowns showing in perfection the arms of young and old individuals, but until all these have been examined in detail, one cannot be certain that they all belong to the above species. As

Zeacrinus (?) Konincki, Bather.

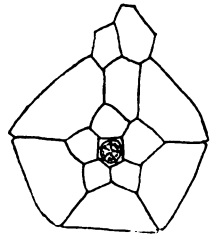

Fig. 7.

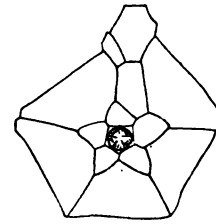

Fig. 8.

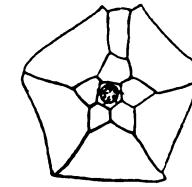

Fig. 9.

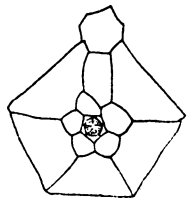

Fig. 10.

Fig. 11.

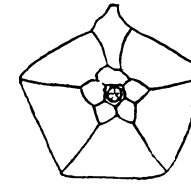

Fig. 12.

Fig. 7—J. W. Colln. 1665*e*. Fig. 8—81*a*. Fig. 9—1665*c*. Fig. 10—81*d*. Fig. 11—408*d*. Fig. 12—990*b*. All × 1⅓.
Specimen 408*d* from No. 1 Bed, Invertiel; others from Roscobie.

regards cups, I have examined 45 specimens from various localities in Fife, and from this examination I am inclined to think that a considerable variation in the anal area will be found to occur in *Zeacrinus* as is the case in *Eupachycrinus*, but perhaps to a different extent. This of course will only be ascertained when a large series is examined. In the meantime the following details may be of interest:—

Of the 45 cups examined—

30 belong to the type represented by 1665e, with slight

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variations up to 81a, which seems to be the extreme form in this series, text figures 7 and 8;

11 belong to the types of 1665c and 81d, also with variations, text figures 9 and 10;

3 belong to 408d, text figure 11;

1 belongs to 990b, text figure 12.

Ulocrinus.

((1506, 2061, 699, and others.))

Under the name *Hydreionocrinus globularis* one finds cups probably belonging to this genus in museums and lists of fossils. As Dr. Bather points out, however, the anal area of these cups does not agree with *Hydreionocrinus*[17] (p. 94), but comes very close to *Ulocrinus*, so that in recent years he has been referring cups of this type to the latter genus. Recently Dr. Bather has published some observations on *Ulocrinus*, particularly with reference to cups of this type found in British rocks.[21] His conclusions are that the majority of the Scottish forms he has handled, including several cups from Fife which I had sent him belong to the elongate form of the *globularis* type. It may be remarked, however, that cups of *Ulocrinus* are common in the Fife limestones, particularly so at No. 1 Bed, Invertiel, zone 19 E. of St. Monans, "Hurlet," Limestone Seafield Tower, etc. (see lists), and show a great diversity of form. Some of them are decidedly conical and may belong to the *nuciformis* type. Until Dr. Bather has seen all the specimens, I have just recorded the name, *Ulocrinus globularis* as being safer and more convenient at present.

Amphicrinus.

((1689, 665, 86.))

Under this genus Dr. Springer has placed a large series of cups and crowns which I previously thought belonged to *Forbesiocrinus*. It is interesting to recall that specimens of this type were probably the first Scottish crinoids to be figured and described as *Encrinus* by Ure.[25] Dr. Springer has now named the species *Amphicrinus Scoticus*, and apparently all the Fife specimens belong to this species. (Dr. Springer's Monograph is not yet out, or at least not yet received in this country.)

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Poteriocrinus.

((118, 1670, 424, 119, 873, 1682, 1693, 643, 465, 1691, 2071, 2070, 662, 2069.))

For lack of fuller information I have been forced to place several cups and crowns under this genus. Some of the cups resemble Phillip's sp. *P. conicus*, others show a variation from that type. Some again belong perhaps to another genus altogether. It is safe to say that when all the specimens are worked out a few additions will be made to the lists.

In the collection is a series of large cups with rugged rugose ornamentation on the plates. Dr. Bather tells me they belong to a *Poteriocrinoid*, and resemble *Poteriocrinus plicatus*, but the plates are much more rugose in surface characters. (See Plates XV. and XVIII.)

Woodocrinus.

((1687, 431, 432, 434, 435, 1609, 429, 430, 121, 123, 438.))

Under this head are a group of specimens, mostly crowns, which are very interesting, especially in the arm structure. The genus is abundant in No. 3 Bed, Invertiel, and the specimens (crowns) range in size from young individuals, 1 inch long, to adult specimens, 3 inches long, some of which have the stem attached. The genus is also abundant at Roscobie. Judging from arm structure and other features, there seem to be two species of the genus in the collection. (Compare Nos. 429 and 430, also see Plate XIX.)

Onychocrinus.

((726, 88, 110, 656, 476, 120, 1522.))

Under this genus is a new species which Dr. Springer has described in his latest Monograph. It is extremely rare to find a complete crown of the species. The one at present in the hands of Dr. Springer is not itself complete, but the best I have yet seen. It was found in No. 3 Bed, Invertiel. As a species, however, it is very abundant in No. 3 Bed, Invertiel, in the form of detached cup and arm plates, and I am not sure but that the same species also occurs in No. 1 Bed at the same locality. Separate cup and arm plates of what looks like the same form do occur in the latter bed here, also the complete bases of what is probably the same or allied species. (See Plate XVIII.)

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Mespilocrinus.

((No. 1 sp. 469, 1613.
No. 2 sp. 2074)).

Cups belonging to this genus occur at No. 1 Bed, Invertiel, in the Seafield Tower Limestone and in Zone 33, E. of St. Monans. Their distinguishing feature is that the whole of the anal area of the cup is occupied by the posterior basal. At first Dr. Bather was inclined to place them under *Graphiocrinus*, but on examination of more material (including a small crown) from Invertiel, which I sent him recently, he concludes they belong to a species *Mespilocrinus Forbesianus*, de Kon, but slightly different. (*Vide* letter, dated 23rd February, 1916.)

Since this note was written, I have found at No. 1 Bed, Invertiel, another cup (No. 2074) which apparently comes under *Mespilocrinus*, but is clearly of a different species from the cups determined by Dr. Bather as near *M. Forbesianus*. These latter are pronouncedly bowl-shaped, with prominent infra-basals. The specimen, No. 2074, while it agrees with the others in the position of the posterior basal which occupies the whole of the anal area, is however a very shallow or saucer-shaped cup; the infra basals are much impressed and scarcely visible, and when the cup is viewed from the side, notches are shown between the radials exactly the same as those figured by Dr. Bather in *Hydreionocrinus Verrucosus*. (See under *Hydreionocrinus*, p. 32.) In the species near *Mespilocrinus Forbesianus* (here called No. 1 sp.) there are no notches. For our purpose the specimen, No. 2074, is here called No. 2 sp.

Cromyocrinus.

((2060, 676, 872, 1529.))

Under this head are a few cups from various localities. Some of them may belong to *Scaphiocrinus* or *Hydreionocrinus*, but in the present state of my knowledge I think it better to let them all stand under the one name meantime.

Hydrcionocrinus.

((1675, 1574, 441, 1673, 136, 846, 847, 686, 96, 97, 2065, 725, 2107, 410, 467b.))

The specimens referred to in this genus consist of a large number of cups and a series of beautifully-preserved crowns,

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some of which show the ventral sac in position. An examination of the cups has shown that in the anal area of *Hydreionocrinus* there does not seem to be the same variation as in *Eupachycrinus* and *Zeacrinus*. Of 50 cups examined (one from Chapel, all the others from Invertiel and Roscobie), 48 belong to the normal type (as exemplified in 2121 ; 1 to 693b and 1 to 1004c), text figures 13, 14, 15, 17, and 18. Among the 48 of normal type there are of course some which show modifications in the shape of the anal plates, but the plan remains the same, that is to say, the

Hydreionocrinus.

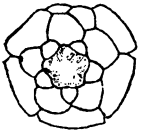

Fig. 13.

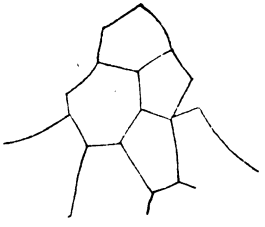

Fig. 14.

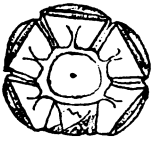

Fig. 15.

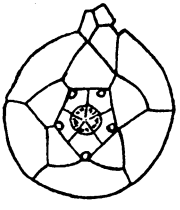

Fig. 16.

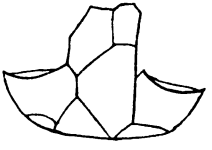

Fig. 17.

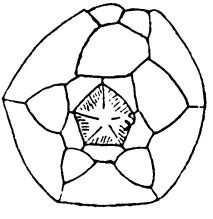

Fig. 18.

Fig. 13—J. W. Colln. 2121 ; $\frac{3}{4}$ nat. size. Fig. 14—2121, anal area × $1\frac{1}{3}$. Fig. 15—2121, $\frac{3}{4}$ nat. size; cup from above, showing excavations between radial facets. Fig. 16—500*x*, diagrammatic view of cup showing position of "knobs" on I.B.B., and anal area × $1\frac{1}{3}$. Fig. 17—693*b*, cup from posterior × $1\frac{1}{3}$. Fig. 18—1004*a* × $1\frac{1}{3}$. 1004*a* from No. 2 Bed, Invertiel; others from Roscobie. Specimens 2121 and 500*x* are of the "knobby" plate type; 1004*a* is of the flat plate type.

anal X is a well-defined plate, quite wide where it comes in contact with the post. B. In only two of those specimens have I so far detected a clear change in the direction of 693b. Fig. 19 (1004c) is a very extreme form, and the only one I have so far come across. In the two specimens near 693b the anal X at its

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Hydreionocrinus.

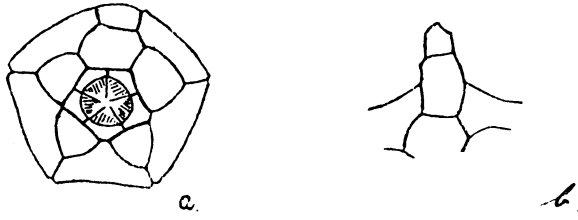

Fig. 19.

Fig. 19—J. W. Colln. 1004c. × $1\frac{1}{3}$ from No. 2 Bed, Invertiel.
a Cup from below; *b* Anal area.
This cup is of the flat plate type.

lower extremity just touches the post. B., and is consequently very much wedge-shaped or triangular at this point. In the normal type of *Eupachycrinus*, this variation is common and in such rounded forms it is often difficult to say whether the R.A. touches the L.P.R. or not. (See Drawing of *Eupachycrinus*, 2098c), text figure 3.

In *Hydreionocrinus*, however, this is not the case so far as concerns the specimens examined, and one has no difficulty in seeing the anal X and its prominent junction line with the post. B. As regards species, it is possible that there may be more than two species in the collection, and this will not be known until all the material has been examined in detail by Dr. Bather. I am not quite sure whether some cups referred to *Cromyocrinus* ought not to be included in *Hydreionocrinus*. These are not included, however, in the above totals. In Dr. Bather's paper [16] he states (p. 75) there are probably two species of *Hydreionocrinus* at Invertiel and Roscobie. I am not quite clear how he differentiates the two. It may be added that in the above summary I have only enumerated separate cups and not cups included in the crowns of which there are several examples in the collection.[19] (See Plates XIII., XIV., and XV.). So far as this somewhat hasty examination allows me to judge, in *Hydreionocrinus* there are two types of cups among the above 50, one bowl-shaped, which I here call No. 1 species (see 2121), text figures 12, 13, and 14, and the other rather more expanding or basin-shaped, here called No. 2 species. In the former the I.B.B.

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are "knobby" plates, if I may call them, *i.e.*, they are irregularly rounded, convex plates, highly curved and ridged. In some specimens each of the I.B.B. has a "knob" or projection on its surface which looks like a stout spine, text figure 16. In the more basin-shaped cups the I.B.B. seem to be relatively larger, quite flat on their surface, and do not show this "knobby" character. Both types of cups have highly ornate plates, and show the characteristic feature of the Fife *Hydreionocrinus*, viz., the junction of the radials with the I.B.B. except in the vicinity of the anal region.

The ventral sac in this genus appears to have been a very massive and somewhat complicated structure. Nearly every crown I have shows indications of it. When a crown is broken across, through the arms, one can see it in section. In the majority of crowns, however, it exists only as detached plates and spines adherent to the tips of the arms. The muscles and attachment for this structure must, I think, have been somewhat intricate. When one examines a crown no indication is seen on the outside of the manner in which the sac plates were attached at the base of the arms to the top of the cup. In the cup of *Hydreionocrinus verrucosus*, figured by Dr. Bather,[20] a notch is shown at the top of the radials. This has led me to re-examine the cups from Roscobie and Invertiel. In those examined I cannot detect a notch, exactly as shown in Dr. Bather's figure. There is certainly a gap between the outer angles of the radials in some of the larger specimens, but in the majority of the smaller or younger individuals the outer angles meet. The gap in these Fife specimens seems, therefore, to be more an effect of growth, and I can see no indications of interbrachial plates. In some of the larger cups when looked at from the side, the gap continues inwards, that is to say, it is not merely a notch between the radials, but an opening between the outer angles of the radials which exposes a groove or excavation occupying a space between the radial facets. In some of the larger specimens the outer angles of the radials meet. In all, when one looks down on the top of the cup, the rather deep and wide excavation, or groove, is clearly seen between the radial facets, corresponding with the gap shown between the radials in some cups. (See Note under *Mespilocrinus*, p. 383.)

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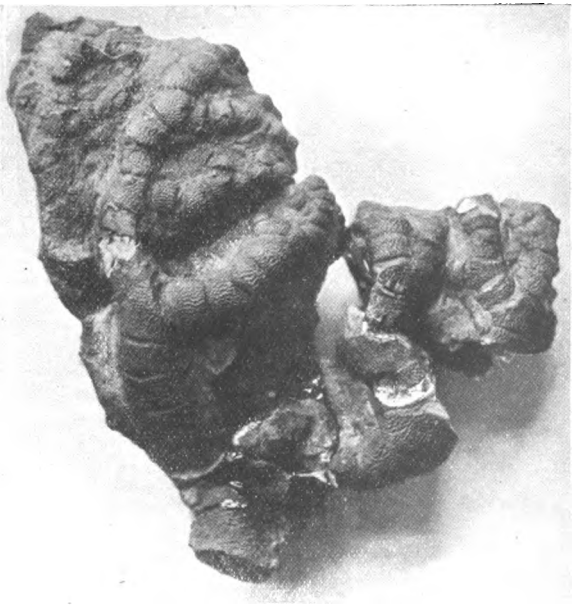
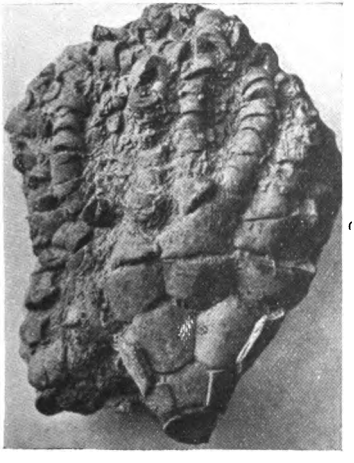


1.—*Onychocrinus*. No. 3 Bed, Invertiel. Natural size.
J. W. Colln., No. 726.



2.—*Poteriocrinus*, Roscobie.
J. W. Colln., No. 1683.
Natural size.

3.—*Poteriocrinus*, Roscobie.
J. W. Colln., No. 1691.
Natural size.

J. Wright, Photo.

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Synerocrinus, Scytalecrinus, Parisocrinus, Decadocrinus, Cyathocrinus.
((664, 691, 2500, 1623, 672, 128, 1615, 113, 109.))

At various times I have had cups and arm fragments and a few crowns referred to the above genera. These names have, however, only been used in the lists when I have been sure of the type. As previously noted additions, including genera like the above, will probably have to be added to the lists. In the meantime, it is better to wait until all the material is worked out.

Tribrachiocrinus.
((2072 A, B, and C.))

This is a very interesting and remarkable genus, only previously recorded from Australia. The Fife specimens, which are at present in Dr. Bather's hands, occur in the calcareous shales which immediately overlie the Tower Sandstone at Seafield. The specimens consist of three cups. The dorsal cup in this genus is composed of three circlets of plates, viz., infrabasals, which are usually three owing to the fusion of two pairs, and this is apparently the case in the above specimens so far as cleaned. Five large basals (in Specimen B there are only 4 owing to the fusion of 2); 5 radials, 3 of which are of normal structure, and evidently bore arms, and 2 which do not seem to have borne arms at all, and whose functions are obscure. In the Fife cups these latter plates are narrow in shape compared with the normal radials. The Australian forms consist of four species, and have been described by R. Etheridge, Jun.[22] (Mem. Geol. Survey, New South Wales, Palæontology No. 5, Sidney, 1892); see review by F. A. Bather,[12] where the characteristics of the genus are explained.

Allagecrinus Austini, Eth. & Carp.
((1508, 2001.))

This is a minute species and only to be found by washing the shales. It is found in numbers in No. 1 Bed, Invertiel, and at Roscobie. At the former locality it is associated with large numbers of the minute and remarkable *Blastoid*, *Astrocrinites Benniei*, R. Eth., Jun. The Fife specimens of *Allagecrinus* agree generally with those described by Etheridge and Carpenter.[23]

The cost of the illustrations has been defrayed by the Carnegie Dunfermline Trust, to whom I tender sincere thanks.

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PROVISIONAL LISTS OF CRINOIDS FROM FIFE.

INVERTIEL, NEAR KIRKCALDY.

1. *Platycrinus*, No. 1 species.
2. ,, No. 2 ,,
3. ,, No. 3 ,,
4. *Allagecrinus Austini*, Eth. and Carp.
5. *Hydreionocrinus*, No. 1 species.
6. ,, No. 2 ,,
7. *Cromyocrinus.*
8. *Woodocrinus*, perhaps 2 spp.
9. *Poteriocrinus*, cf. *conicus.* Phill.
10. ,, near *plicatus* (Dr. Bather in litt., see page 27).
11. ,, species.
12. *Eupachycrinus*, No. 1 species.
13. ,, No. 2 ,,
14. *Zeacrinus Konincki*, Bather.
15. "*Ulocrinus globularis.*"
16. *Amphicrinus Scoticus*, Springer.
17. *Onychocrinus*, sp. nov., Springer.
18. *Mespilocrinus*, No. 1 species (near *Forbesianus*, de Kon.).
19. ,, No. 2 ,,
20. *Rhodocrinus*, No. 1 species.
21. ,, No. 2 ,,
22. ,, No. 3 ,,

Also the *Blastoid Astrocrinites Bennici*, which is very abundant in No 1 Bed.

SEAFIELD TOWER, NEAR KIRKCALDY.

1. *Platycrinus*, No. 1 species.
2. ,, No. 2 ,,
3. ,, No. 3 ,,
4. *Eupachycrinus*, No. 1 species.
5. ,, No. 2 ,,
6. *Amphicrinus Scoticus*, Springer.
7. *Synerocrinus* (*Forbesiocrinus incurvus*, *Trautchold*, near
[1] See Postscript to (19), p. 161.
8. *Mespilocrinus*, No. 1 species (near *Forbesianus*).
9. ,, No. 2 ,,
10. *Hydreionocrinus*, No. 1 and No. 2 species.
11. *Zeacrinus Konincki*, Bather.
12. *Cromyocrinus* or *Hydreionocrinus.*
13. "*Ulocrinus globularis.*"
14. *Woodocrinus.*
15. *Rhodocrinus*
16. *Poteriocrinus*, cf. *conicus*, Phill.
17. *Onychocrinus*, sp. nov., Springer.

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SHALES ABOVE TOWER SANDSTONE, SEAFIELD, KIRKCALDY.

1. "*Ulocrinus globularis.*"
2. *Cromyocrinus* or *Hydreionocrinus.*
3. *Tribrachiocrinus.*

SHALES ABOVE FAULTED "HOSIE" LIMESTONE, SEAFIELD, KIRKCALDY.

1. *Woodocrinus.*

POTMETAL, NEAR KIRKCALDY.

1. *Hydreionocrinus.*
2. *Woodocrinus.*

BOGIE, NEAR KIRKCALDY.

1. *Hydreionocrinus*, No. 1 species.
2. ,, No. 2 ,,
3. *Poteriocrinus.*
4. *Woodocrinus.*

CHAPEL, NEAR KIRKCALDY.

1. *Hydreionocrinus*, No. 1 species.
2. ,, No. 2 ,,
3. *Poteriocrinus.*
4. *Eupachycrinus*, No. 1 species.
5. ,, No. 2 ,,
6. *Zeacrinus Konincki*, Bather.
7. *Amphicrinus Scoticus*, Springer.

CLATTERING WELL, BISHOP HILL, KINNESSWOOD.

1. "*Ulocrinus globularis.*"
2. *Poteriocrinus.*
3. *Eupachycrinus*, No. 1 species.
4. *Zeacrinus Konincki*, Bather.

TEASSES, NEAR LARGO, AND CULTS, NEAR LADYBANK.

1. *Zeacrinus Konincki*, Bather.
2. "*Ulocrinus globularis.*"
3. *Amphicrinus Scoticus*, Springer.
4. *Poteriocrinus.*

} These four species occur at both localities.

ROSCOBIE, NEAR DUNFERMLINE.

1. *Platycrinus*, No. 2 species.
2. ,, No. 3 ,,
3. *Eupachycrinus*, No. 1 species.
4. ,, No. 2 ,,
5. *Rhodocrinus*, No. 1 species.
6. *Poteriocrinus plicatus* (Dr. Bather in litt., June, 1915).

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7. *Poteriocrinus* cf. *conicus*, Phill.
8. ,, sp.
9. *Cromyocrinus.*
10. *Synerocrinus* sp., Springer.[1]

[1] See Postscript, *Trans. Edin. Geol. Soc.*, vol. x., pl. ii., p. 161.

11. *Amphicrinus Scoticus*, Springer.
12. *Parisocrinus* or *Decadocrinus.*
13. *Hydreionocrinus*, No. 1 species.
14. ,, No. 2 ,,
15. *Woodocrinus* (perhaps 2 spp.)
16. *Zeacrinus Konincki*, Bather.
17. "*Ulocrinus globularis.*"
18. *Cyathocrinus.*
19. *Allagecrinus Austini*, Eth. and Carp.

ARDROSS, NEAR ELIE.

1. *Synerocrinus* (near *Forbesiocrinus incurvus Trautchold*).
2. *Rhodocrinus.*
3. *Poteriocrinus* (near the type of Phillip's *conicus*, with smooth plates).
4. ? *Poteriocrinus* (stem, cup, and armplates, ornamented with mosaic-like pattern).
5. ? *Poteriocrinus* (smooth plates, long arms, and prominent anal tube).
6. *Cromyocrinus* (saucer-shaped cup, smooth plates, arms with long pinnules).*

* Mr. Dunlop has a fine specimen from this locality showing these characteristics.

2ND ABDEN LIMESTONE, NEAR KINGHORN.

1. "*Ulocrinus globularis.*"

LIMEWORKS, NEAR LESLIE.

1. *Poteriocrinus* cf. *conicus*, Phill.

LIMESTONE, WEST-END, ST. MONANS (WESTERN LIMB OF SYNCLINE).

1. *Hydreionocrinus* sp., crowns and cups.
2. "*Ulocrinus globularis.*"
3. *Eupachycrinus*, No. 2 species.

ZONE 33, EAST OF ST. MONANS (EASTERN LIMB OF SYNCLINE).

1. *Platycrinus* sp.
2. *Mespilocrinus*, near *Forbesianus*, de Kon. (No. 1 species).
3. *Bursacrinus* or *Delacrinus.*

ZONE 33, IN FRONT OF ST. MONANS (WESTERN LIMB OF SYNCLINE).

1. *Mespilocrinus*, No. 1 species.
2. *Bursacrinus* or *Delacrinus.*

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ZONE 19, EAST OF ST. MONANS.

1. "*Ulocrinus globularis.*"

CHARLESTOWN, NEAR DUNFERMLINE.

1. *Zeacrinus Konincki*, Bather.
2. "*Ulocrinus globularis.*"
3. *Poteriocrinus* cf. *conicus*, Phill.
4. ,, sp.

DULOCH, NEAR DUNFERMLINE.

1. *Platycrinus*, No. 1 species.
2. ,, No. 3 ,,
3. *Zeacrinus Konincki*, Bather.
4. *Eupachycrinus*, No. 1 species.
5. *Amphicrinus Scoticus*, Springer.
6. "*Ulocrinus globularis.*"
7. *Poteriocrinus* sp.

COWDENS, NEAR DUNFERMLINE.

1. *Platycrinus*, No. 1 species.
2. ,, No. 2 species.
3. "*Ulocrinus globularis.*"

STENTON, NEAR THORNTON.

1. "*Ulocrinus globularis.*"

TIEL BURN, BELOW GOLF CLUBHOUSE, NEAR KIRKCALDY.

1. "*Ulocrinus globularis.*"

LIST OF LITERATURE IN WHICH REFERENCE IS MADE TO FIFE CRINOIDS OR LOCALITIES GIVEN IN THIS PAPER.

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R. Ure.
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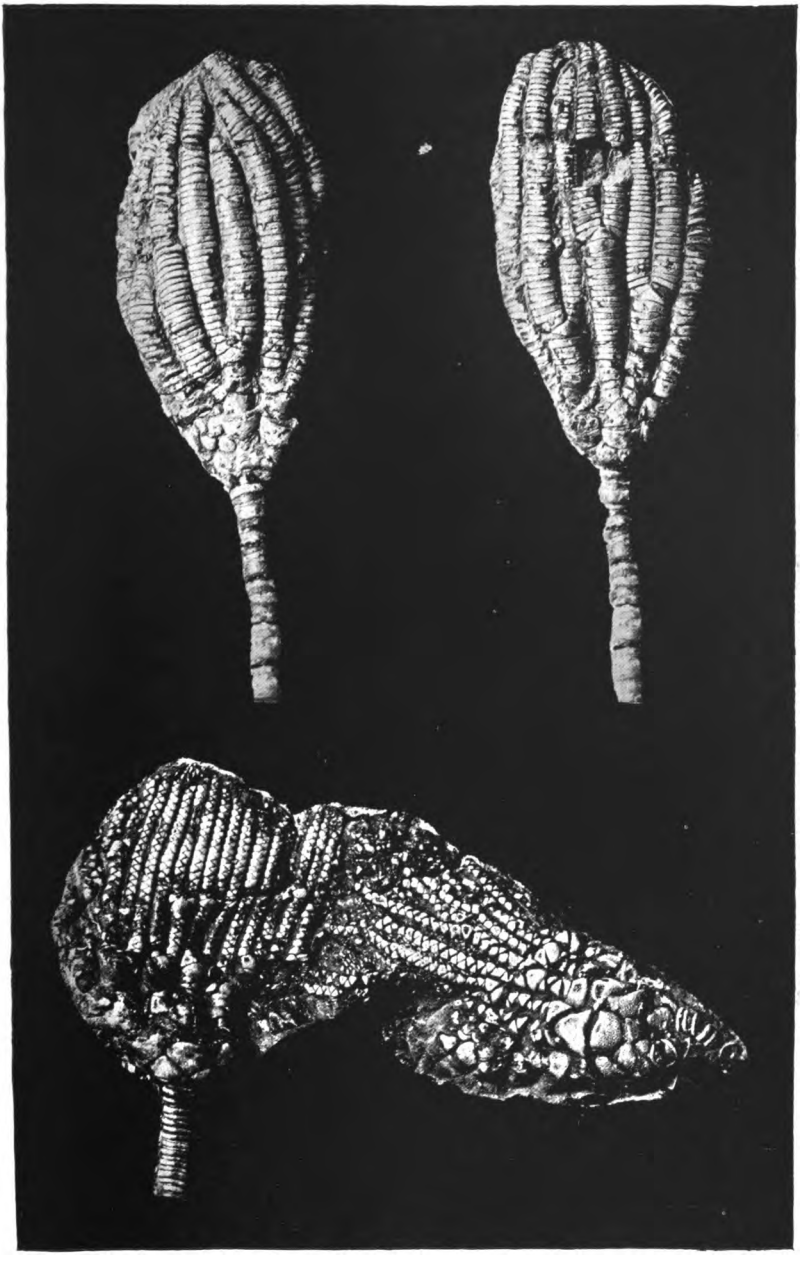

Top Figures—*Woodocrinus* sp., No. 3 Bed, Invertiel. Posterior and Anterior views. Specimen No. 429. J. Wright Colln.

Bottom Figures—*Hydreionocrinus* sp. Shales above "White" Limestone, West end St. Monans. Specimen No. 2087. J. Wright Colln. All figures natural size.

J. Wright, Photo.

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No. XX.—The Micro-Examination of Refractory Materials.

By Alexander Scott, M.A., D.Sc.

Introduction.

The methods used in the microscopical examination of inorganic materials may be grouped into two classes, those involving the examination of a flat, generally polished, surface by reflected light and those in which a transparent section is examined by transmitted light. The development of these two methods is largely due to the work of H. C. Sorby who, by grinding and polishing pieces of steel and examining the structure of the prepared surfaces, founded the science of metallography, and who also, by investigating microscopically the structure of sections of rocks ground sufficiently thin to be transparent, laid the foundations of modern petrology. In recent years the former method has been very successfully applied to the investigation of the opaque minerals which constitute many ore-bodies, while the latter has been utilised in the investigation of refractories, glass and so forth. In general the one method is used for opaque materials and the other for materials which can be rendered transparent or translucent.

In the metallographic method, the only factors available in practice for the identification of the constituents of the material under examination are the grain-structure, the relative hardness and the behaviour towards etching agents. While the first of these is of considerable value so far as metals are concerned, it has to be used with caution in the examination of refractories, owing to the fact that different constituents may develop similar habits, while some may occur in the form of pseudomorphs. Hardness is likewise of little use, except for the identification of such minerals as quartz and corundum. In the examination of metals and ore-minerals, the behaviour of the constituents towards etching agents is largely utilised, but such a procedure

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is not of much value in the case of refractories, since many of the commonly occurring constituents are not attacked by ordinary reagents and the comparative effects are not sufficiently great in the case of such agents as hydrofluoric acid.

In some cases, however, this method can be used for the identification of certain constituents, such as fayalite (ferrous orthosilicate) in silica bricks which have been in use in a steel furnace. On treating fayalite with hydrochloric acid, the silicate is broken up, and the iron goes into solution, the silica being left in the form of a gel, which can be made to absorb such dyes as malachite green. Hence the treatment of such a brick with hydrochloric acid and a solution of a dye should allow the discrimination of fayalite, since none of the other materials present is attacked appreciably by the acid. The usual method of etching silicates is to treat successively with the acid and the dye, with an intermediate and final washing. The following procedure, however, gives equally good results. A quantity of malachite green is dissolved in dilute hydrochloric acid to form a red solution and the ground and polished surface of the brick treated with this solution. When the etching has gone on for a few minutes, the solution is washed away by allowing a jet from a wash-bottle to impinge on the surface a short distance from the part under examination. After the acid is washed off, the silica of the decomposed mineral remains behind in the form of a gel, stained green with dye, and, if the washing is carried out with sufficient care, the gel occupies the position of the decomposed mineral. The same procedure can be applied to thin sections and used not only for certain constituents of igneous rocks, such as the felspathoids, but also in the examination of thin sections of refractories.

The chief advantages of the application of the metallographic method to refractories are concerned with the investigation of texture rather than constitution. The texture of a brick can be examined by grinding a flat surface, cementing a glass slip to it by means of Canada balsam or coating it with a transparent varnish and examining it by means of a lens or a low power microscope. This method also allows the discrimination of very fine detail to a much greater extent than does the petrological method. Examination by means of a high-power objective such as a 2 mm. oil immersion lens is much more easy

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in the former case than in the latter, owing to the fact that the thickness of a transparent section interferes with exact focussing. With such an objective only a very thin layer is in focus at any one time and, with transmitted light, the image is confused by the layers immediately above and below. This is particularly noticeable in photomicrography. In the case of refractories, however, the difficulty of preparing a good surface generally inhibits the discrimination of very fine detail.[34]

So far as the identification of the constituents is concerned, the petrographic method is incomparably the better, owing to the fact that it allows the determination of the optical properties such as refractive index, double refraction, and so forth. In thin section, by means of the Becke or Schröder van der Kolk method, the relation of the refractive index to that of Canada balsam can be investigated, the double refraction can be quantitatively determined from the interference colours, provided the thickness of the section is known and, in most cases, the crystal system of the mineral fixed. The refractive index of any constituent can be determined with considerable accuracy by immersing the powdered material in liquids of known refractive index, and comparing the latter with that of the mineral by either of the methods mentioned above. Even where the grainsize of the constituents is too small for the use of the Becke method, results can often be obtained from the "dark ground" illumination method of van der Kolk. Prior to such an examination it is often convenient to separate the ground material according to specific gravity by means of such heavy liquids as bromoform, methylene iodide, &c.

In some cases the quantitative determination, under the microscope, of the amount of the various constituents in a refractory may be of some importance. For example, the amount of conversion of the quartz of a silica brick to one or other of the high temperature forms cannot be determined by chemical analysis, since no change in composition is involved, nor, with any degree of exactness (see later), by specific gravity determinations, owing to the influence of the non-siliceous impurities. In general, however, this can be determined by quantitative misroscopical measurement on a thin section.[33] Sorby estimated the amount of the various minerals in a rock by drawing typical "fields" with the aid of a camera lucida,

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and then cutting out of the drawing the different grains and weighing them. This method of areal measurement, however, has now been superseded by one of linear measurement, which was devised by Rosiwal and has been successfully applied to refractories. The time taken to determine, say, the amount of quartz in a silica brick can be shortened and the accuracy of the measurements greatly increased by the use of the instrument devised by Shand.

There is no particular difficulty in the preparation of thin sections of refractories.[32] The latter are certainly more friable than most igneous rocks,[9] but not more so than many sedimentary rocks and, if the precautions usually adopted in the case of the latter, such as a preliminary soaking in hot Canada balsam and greater care during grinding, be taken, sections comparable in thinness to those of sedimentary rocks can be easily prepared. This is particularly the case with silica and magnesite bricks, both used and unused, but often it is more troublesome to grind fireclay materials sufficiently thin to be transparent. This is due rather to the opacity of the material than to any difficulty in grinding to the ordinary thickness (·01 to ·04 mm.).

In the following pages a short description is given of the results obtained from the micro-examination of such refractory materials as silica, magnesite, zirconite and firebricks both in the unused condition and after use in various types of furnaces. Some notes are also added regarding the results of the investigation of the action of various furnace dusts and so forth on refractories, where such action has been studied with the aid of micro-examination.

Silica Refractories.

The Various Forms of Silica.—Silica is known to exist in more crystalline forms[8] than any other oxide. The work of C. N. Fenner[10] has demonstrated beyond doubt the existence of at least seven crystalline modifications in addition to several amorphous and hydrated types, and is the source of most of our knowledge concerning the relative stability of the former. The form stable at ordinary temperature is α-quartz,

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but this, when heated, undergoes a reversible transformation at 575°C. to β-quartz. The latter is stable up to 870°C., but above that temperature passes with the aid of a flux to β_2-tridymite. At 1470°C. β_2-tridymite, again in the presence of a flux, changes to β-cristobalite which melts at 1710 ± 10°C. (Ferguson & Merwin[12]). On cooling β-cristobalite rapidly from its stable region, it can be undercooled, and this undercooled material is transformed at a temperature between 200° C. and 270°C. to α-cristobalite. Similarly β_2-tridymite can be undercooled and is converted at 163°C. to β_1-tridymite and the latter at 117°C. to α-tridymite. There are thus four stable modifications, α- and β-quartz, β_2-tridymite and β-cristobalite, and three metastable modifications, β_1- and α-tridymite, and α-cristobalite. Similarly the inversions may be divided into two types, one comprising the α-β transformations which are rapid and reversible, and cannot be inhibited to any extent, and the other comprising the β-quartz—β_2-tridymite, β_2-tridymite —β-cristoblaite changes, which are very sluggish and, so far as the pure substance is concerned, practically irreversible under normal cooling conditions. The melting point of β_2-tridymite is somewhat lower than that of cristobalite, and lies in the neighbourhood of 1670°C.

By rapid cooling from a temperature above the melting point the amorphous form silica-glass can be made to persist to ordinary temperatures. The β-forms, however, cannot persist below their transformation points as, no matter how quick the cooling, the inversions to the α-forms always occur. On the other hand, although such modifications as α-tridymite and α-cristobalite are theoretically unstable at ordinary temperatures, they can exist for an indefinitely long period without undergoing any inversion to the stable form α-quartz.

Fenner's interpretation[11] of his work on the stability of these forms has not found universal acceptance, and the evidence against it is partly based on the phenomena observed in silica bricks. Le Chatelier[21] considers that tridymite is the form stable at the highest temperatures and that cristobalite is in general unstable. The present writer[32] holds that the transformation point of β_2-tridymite to β-cristobalite is not lower than 1570°C. At the latter temperature tridymite is slowly inverted to

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cristobalite without the aid of a flux, but below that temperature the inversion will only proceed with the aid of some solvent such as molten silicates, sodium tungstate and so forth. Hence it seems better to postulate that tridymite is stable to at least 1570° C. and to explain the transformation below that temperature as due to solution of the tridymite by the flux and reprecipitation of the dissolved silica as the unstable form cristobalite.[34] Such a formation of an unstable intermediate form is by no means uncommon.

The importance of these transformations, so far as refractory materials are concerned, lies in the volume changes[37] which accompany them. Since the specific gravities of quartz, tridymite and cristobalite are respectively 2·65, 2·27 and 2·33, the conversion of quartz to tridymite involves an expansion of 16 per cent. by volume, of quartz to cristobalite 13 per cent., and of cristobalite to tridymite, 3 per cent., ignoring for the moment the α-β inversions. Hence, as tridymite is generally the ultimate form which develops during use, the theoretical expansion from the *green* to the final state is 16 per cent. In actual practice it is generally greater than this and may amount, in extreme cases, to 40 per cent. This excess over the theoretical amount is due to an increase in the amount of pore-space, that is, to the fact that the transformation does not take place with a minimum of volume change owing to the way in which the new formed tridymite is orientated. The slower the rate of heating during the conversion, the smaller is the excess over the theoretical expansion, with rapid heating to a temperature of about 1550°C. the conversion may be accompanied by a very large volume change.

Since the α-β charges are reversible and cannot, so far as is known, be inhibited, they must occur every time the brick is heated or cooled through the inversion temperatures; since the change of volume which accompanies them is likewise inevitable and becomes a matter of considerable importance. According to Le Chatelier, the "α-β" expansion in the case of quartz is ·44 per cent., in cristobalite ·97 per cent., and in tridymite, ·15 per cent. The greater the proportion of tridymite in a brick, the smaller will be the volume change in heating or cooling through a temperature range which includes the α-β inversion

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temperatures. Hence a brick containing much tridymite has a lower liability to spalling than one mainly cristobalite or quartz.

In most cases, after kiln-burning, a silica brick still contains from 20 to 70 per cent. of unconverted quartz,[34] while in the converted material, the relative proportion of tridymite and cristobalite may vary within wide limits.[25] Hence a knowledge of the amounts of the various forms[17] present in a brick may give some clue to the future behaviour of the latter under conditions of high temperatures. The only method which will yield this information is micro-examination. Attempts have been made to determine the proportions of quartz, tridymite, &c., from specific gravity determinations, but the results have too large a probable error to be of much use.[35] In some cases a knowledge of the so-called "true" specific gravity may give an approximate notion of the amount of quartz present, but it is practically of no value so far as the discrimination of the high temperature forms are concerned.

Methods of Identification[35].—Since the β-modifications never persist to ordinary temperatures, it is necessary to consider only the α-forms. Of the various physical properties which can be made use of, for purposes of identification under the microscope, the simplest are crystal form and the optical properties. Of the latter the refractive index and the double refraction are the most useful, as the individual crystals are generally too small for the determination of the other optical properties.

So far as crystal form and habit is concerned, in silica bricks quartz usually appears in the form of rounded allotriomorphic grains. In certain cases where the quartz rocks which have been used show secondary growths in the original grains of quartz, the crystals of the latter in the rock fragments in the brick may have definite hexagonal outlines. Tridymite occurs often as lath or wedge-shaped crystals either singly or multiply twinned and at other times as small overlapping plates. Cristobalite is occasionally found as well developed skeletal crystals, but in general it occurs as minute rounded or pseudohexagonal grains. When the twinned crystals are wedge-shaped the extinction is always parallel to the outer edge and not to the trace of the plane of contact of the two individuals of the twin. The habit, however, is not a trustworthy

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guide as both tridymite and cristobalite tend to occur as pseudomorphs after each other. The pseudohexagonal grains are probably pseudomorphs after cristobalite. This is borne out by the fact that they usually occur in those parts of the brick which has most recently been converted, that is, in the quartz grains, as will be shown later, generally. These invert first to cristobalite, which later transforms to tridymite, which is the stable modification under the general conditions in practice. Since none of the three forms possess a well-defined cleavage, the latter cannot be used as a diagnostic criterion.

Refractive index, however, affords a more reliable method of discrimination. Quartz has a mean refractive index of 1·549 slightly above that of Canada balsam, while the mean refractive indices of cristobalite, 1·484, and tridymite, 1·477, lie well below that of Canada balsam. Hence quartz may be easily distinguished from the other two, either in thin section or in the form of powder. The low refractive indices of the high temperature forms make the crystals stand out in relief in sections mounted in Canada balsam.

For the discrimination of tridymite and cristobalite, an immersion method gives the best results. If the crystals are of sufficient size, the Becke method may be used. Fragments of the material to be examined are immersed in a liquid whose refractive index lies between 1·477 and 1·484 and the movement of the bright line in raising the tube of the microscope indicates whether the refractive index of the crystals is higher or lower than that of the liquid; if the former, the crystals are cristobalite, if the latter, tridymite. For smaller fragments, the methods of Schröder van der Kolk are more easily applied. The estimation of the relative refractive indices of the crystal fragments and liquid depends on the colour of the fringes which appear with dark ground illumination. If the crystal and liquid have the same refractive index for some wavelength near the middle of the visible spectrum, the fringes are coloured blue, but if the crystals have a slightly higher refractive index the fringes are coloured red. Hence if a mixture of tridymite and cristobalite be immersed in a liquid of refractive index, 1·477, the fringes round the tridymite will be blue and those round the cristobalite reddish. Quartz in the same liquid will show white

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colours. Hence by this means the three forms may be discriminated. The most suitable liquid is a solution of potassium mercuric iodide in water, the refractive index being varied by changing the dilution. As is the case with most such liquids, the solution requires to be frequently standardised, owing to the water content varying by evaporation and absorption. The effect of changes of temperature on the refractive index of the liquid may also have to be taken into account.

The double refraction of quartz (·007) also serves to distinguish it from the other forms. Tridymite has a double refraction of ·004, while that of cristobalite is somewhat lower. The data for the latter are somewhat conflicting, but in general the double refraction of cristobalite is so low as to be only distinguishable with the aid of a selenite plate.

Microstructure of Silica Rocks.—The rocks which have been used for the manufacture of silica bricks, comprise quartzites, vein quartz, ganisters, various types of silicified sandstones and grits and cherts. So far as this country is concerned metamorphic quartzites are little used, but on the continent of Europe[20] and in America[36] quartzites ranging in age from Archean to Silurian have been tried. These generally consist of more or less angular quartz grains in a scanty siliceous matrix. So far as British practice is concerned, metamorphic quartzites have met with little success. The lack of a non-siliceous matrix in the rock hinders the conversion of the quartz during the kiln-burning and renders the brick liable to spall[15] and to have a high after-expansion. In America this is partly obviated by the use of higher temperatures and more prolonged firing. Vein quartz is even more troublesome, as it generally consists of relatively large interlocking crystals with an absence of non-siliceous cement.

The ganister rocks[39] of the South Yorkshire coalfield which is generally supposed to give the best silica bricks, consists essentially of angular quartz grains in a matrix mainly siliceous, but with the non-siliceous materials very well distributed so that the conversion is greatly facilitated. The Dinas-rock of South Wales consists of sub-angular grains of quartz in a highly siliceous matrix, the total amount of non-siliceous material being often very small. Many Carboniferous sand-

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stones containing a secondary quartzose matrix also give good results, but the occurrence of rounded quartzose grains, or a tendency for the rock to break up to subangular or rounded fragments is a factor which is often objectionable. Some of the rocks used in Germany[30] contain a fair proportion of apparently amorphous material in the matrix[40], but there is no reason to suppose that such materials give a better product[42] than those from which the amorphous groundmass is absent. In some parts of Europe typical quartzites of metamorphic aspect[34] are used. These are composed of a mosaic of interlocking quartz-crystals,[16] sometimes with a slightly schistose structure, although the latter is considered to be detrimental.[19] Many of the rocks used in America[36] are similar. So far as is known, the best materials are those rocks with angular quartz grains and the non-siliceous material small in amount, but uniformly distributed. Other rocks with appropriate chemical composition can, however, furnish useful refractory material,[13] provided suitable methods of manufacture are adopted.

Microstructure of Unused Silica Bricks.—The chief points of interest which result from the micro-examination of unused silica bricks are the degree of conversion of the quartz to the high temperature forms and the mode of this conversion. During the firing the fine-grained silica of the matrix reacts with the lime which has been added and forms compounds which ultimately become molten during the final stages of burning. The nature of these salts varies with the composition of the original rock, but essentially they consist of silicates of lime, iron, and magnesia. This matrix occurs not only in the areas between the rock fragments but also throughout the latter, along the boundaries of the original quartz crystals; that is, wherever there is any non-siliceous cementing material. The conversion of the quartz generally proceeds with the aid of this molten matrix. The quartz is dissolved by the latter and reprecipitated as cristobalite. Hence the amount of cristobalite present after firing depends on the nature and distribution of the matrix and the temperature and duration of firing. If the firing be prolonged, some of the cristobalite may change to tridymite.

An unused brick, therefore, is seen under the microscope to

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consist of fragments of quartz rock in a matrix partly glassy and partly composed of cristobalite. The fragments are still mainly quartz, but contain a network of cristobalite and glass along the boundaries of the quartz crystals. With harder firing, the rock fragments begin to undergo peripheral alteration, the layers of cristobalite throughout the former tend to become wider, while crystals of tridymite begin to appear in the matrix. If the brick be heated until all the quartz is converted, the rock fragments can still be delineated, as they usually consist of very fine-grained aggregates of cristobalite and glass, while the matrix is composed of well-formed tridymite with very subordinate cristobalite.

The conversion therefore proceeds by the solution of the quartz in the matrix, followed by the deposition from the latter of cristobalite as an unstable intermediate phase, and the final conversion to the stable form tridymite. The intermediate existence of cristobalite is further shown by the fact that tridymite often occurs in the forms of small crystals pseudomorphous after the former. The effect of further treating is to induce the coalescence of these into larger crystals with typical wedge-shaped form.

If a piece of silica brick be cooled rapidly from a temperature in the region of 1500° C., a certain amount of clear glass is visible in the matrix. If the same piece be reheated and allowed to cool slowly, skeletal crystals of cristobalite appear in the glass; these represent an excess of silica which was in solution in the former case. The various stages of the conversion can be studied by examining the different parts of bricks from the roof of a steel furnace, as has been done by Rengade,[27] Scott,[34] Graham,[14] Stead,[38] and others.[7]

The determination of the proportion of residual quartz after kiln-firing gives in most cases a fair indication of the amount of "after-expansion" which the brick is likely to undergo during use at high temperatures. The greater the proportion of residual quartz the greater the after-expansion. So far as this country is concerned, the proportion of residual quartz in commercial silica bricks varies from 35 to 55 per cent., but in some cases where the burning has been more intense it may be lower. In American practice,[36] where the firings

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temperature is generally higher and the burning more prolonged than in this country, the proportion varies from 20 to 30 per cent. Tables showing the proportion of quartz in various types of unused bricks have already been published.[34] In addition to the firing conditions the chief factor which influences the amount of conversion is the amount, nature, and distribution of the impurities.[35] In general those impurities which combine with silica to give a fusible mixture with low viscosity are much more potent agents than those whose melts have a high viscosity. Thus lime or oxide of iron, or a mixture of these, gives a much greater conversion than alumina; each of the former combines readily with silica to give liquids of relatively low viscosity, but the latter, on the other hand, does not give easily fusible mixtures with silica, even the silica-sillimanite eutectic having a melting point in the region of 1600° C.

Micro-examination of Used Bricks.—As mentioned above, several descriptions of the microstructure of bricks from the roofs of various types of steel furnaces have been published. The chief points of interest are concerned with the capillary ascent of oxides of iron, which apparently push in front of them the lime silicates of the bond. This local concentration of these salts in those parts of the brick to which the iron has not penetrated results in a greatly increased conversion of the quartz, so that the latter, which at the cool end of the brick is in approximately the same proportion as in unused bricks, rather suddenly diminishes to zero in the parts immediately adjacent to the black portions.

The chemical interaction[1] between the oxides of iron and the matrix is negligibly small,[24] as micro-examination shows that practically no silicate of iron, such as fayalite, is present, while magnetite[6] and tridymite occur side by side, the whole structure sometimes resembling the ophitic structure of certain igneous rocks. This absence of interaction is probably similar to the state of affairs in many granites, where the iron oxide crystallizes out as magnetite, although abundant free silica may be present.

Where the bricks in steel furnaces have been subjected to reducing conditions, however, silicates of iron may develop.

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Thus thin sections of material taken from the parts of furnaces[34] show often a fair amount of fayalite, occurring along with tridymite, cristobalite, and unaltered quartz. In this case unconverted quartz is commonly found in the parts impregnated with iron oxides. The co-occurrence of fayalite and silica is interesting, as it indicates that under these conditions the metasilicate of iron is not stable. This may account for the absence of the latter in a pure condition in natural rocks as well as the occurrence of olivine rich in iron in certain acid rocks.

Micro-examination has also been utilised in investigating the effects of various types of flue dusts and salts on silica bricks at high temperatures. The dust reacts with the fine material in the matrix of the brick, but in general does not attack to any extent the larger fragments. The products formed by the reaction of the dust and the matrix vary with the nature of the former and the conditions, and include such silicates as fayalite and willemite in the case of dusts rich in oxides of iron and zinc respectively. The quartz of the matrix is usually replaced by tridymite. In some cases the structural relations of the latter to the magnetite which is present suggest analogies with certain types of clays. In other cases where, for example, the corrodant is a mixture of lime and alkali silicates, the reaction between the brick and dust is so complete that only slight traces of the original structure remains, the brick having fused to a glass and partly recrystallised as cristobalite.

Similar phenomena can be observed in silica bricks which have been in the crown of a glass furnace. The alkali vapours and dust which penetrate these react with the matrix to form a fairly fusible melt; this dissolves the quartz and reprecipitates it as cristobalite or tridymite.

The alkali vapours and dust which penetrate these react with the matrix to form a fairly fusible melt; this dissolves the quartz and reprecipitates it as cristobalite or tridymite.

A microscopic investigation of bricks which have been melted gives some indication of the phenomena which occur when such a brick is fused. In some cases, where the bond forms a fairly fusible mixture with the fine-grained silica, the brick may soften although a large proportion of the silica may still

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be crystalline. This is particularly the case where the non-siliceous constituents are mainly lime, magnesia, and so forth. A section of such a brick after it has melted, especially "under load," shows a glassy matrix in which are embedded masses of crystalline tridymite, or cristobalite; these represent the original rock fragments. Where, on the other hand, the impurity is mainly oxides of iron or alumina, a thin section shows that both the matrix and the rock fragments have fused more or less simultaneously. This suggests that in some cases the collapse of silica refractories at high temperatures is due to the load overcoming the viscosity of a fused matrix and not to the fusion of the brick on a whole.

Other Refractory Materials.

In the case of the refractory materials composed of fireclay, magnesite or zirconite, the scope for microscopic investigation is much more limited. This is partly owing to the fact that the materials are often amorphous or very fine-grained and partly to the absence of polymorphism in the compounds composing the refractories. In certain types of investigation, however, the microscope does furnish considerable information.

Fireclay Refractories.—When a material composed of fireclay is subjected to heat, it undergoes several changes. The clay substance, after the loss of the hygroscopic water, breaks up to give the three constituent oxides in free form, water, silica, and alumina; later the alumina undergoes polymerization, and finally combines with an equal molecular proportion of silica to form sillimanite.

The silica and alumina which are thus set free at a temperature in the region of 500° C. are probably amorphous, but prolonged heating at higher temperatures converts them to the crystalline forms. The sillimanite which begins to develop at temperatures above 1100° C. is generally crystalline, and can be readily distinguished under the microscope. Thus a firebrick which has been subjected to a high temperature for a considerable period shows under the microscope numerous acicular crystals of sillimanite in a dusty matrix. The latter is composed of glass in which are set innumerable "longulites" of the aluminium silicate. The statement by Cox[43] that these

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mineralogical changes only commence when the fireclay is heated to 1500° C. is not borne out by the occurrence of sillimanite, as shown by Vernadsky[54] and Mellor,[46] in porcelain which has never been subjected to temperatures higher than 1200° C. The work of Sokolov[52] shows that the oxides set free by the break-up of the clay substance are most probably amorphous and the sillimanite develops by the combination of this amorphous alumina and silica. By heating a fireclay to a temperature of 1700° C. for a few hours comparatively coarse crystals can be obtained and these, as measured microscopically, may amount to 50 per cent. by volume of the heated material. (Pl. xx., Fig. 1.) According to Cox,[43] the sillimanite thus formed has the composition 11 Al_2O_3 ; 8 SiO_2, a statement which is not in agreement with the work of Shepherd and Rankin,[51] who found, that although corundum take up some of the silicate in solid solution, sillimanite always developed in a pure condition. The present writer has also been unable to confirm Cox's results by the chemical examination of clay heated to 1700° C. In some cases the glass tends to devitrify to give cristobalite. The corrosion of quartz, when present in clays which have been subjected to high temperatures, has been investigated by Ries and Ornouye.[49]

It has been argued that the proportion of sillimanite present gives some indication of the temperature which the material has attained, and hence furnishes a method of determining that temperature. This, however, is not the case, since a short firing at a high temperature may give the same product as a more prolonged heating at a lower temperature.

Some interesting results have been obtained from the examination of thin sections of fireclay materials which have been subjected to various corroding agents. Thus Wilson[55] has very successfully applied petrographic methods in the investigation of certain glass furnace products and has noted the occurrence, in firebricks and fireclay blocks which have been contaminated by molten glass, of corundum, sillimanite, felspar, magnetite, biotite, &c.

Similarly, the investigation of zinc retorts[50] and other fireclay materials from zinc furnaces has shown the presence of tridymite gahnite (zinc spinel),[53] willconite, fayalite, &c., and yielded some information regarding the reactions which occur between the charge and the material of the retort. The forma-

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tion of silicates of zinc and iron in a somewhat analogous fashion has also been demonstrated experimentally by allowing mixtures of zinc and iron compounds to impinge on various types of firebrick at high temperatures.

The changes which occur when clays are heated have also been investigated in the case of porcelain, which has been proved by Mellor,[45] Klein[44] and others[47 48 56] to contain sillimanite. Marquadt porcelain has also been investigated microscopically.[45]

Magnesite Refractories.—The raw materials used in the manufacture of magnesite bricks after calcination contain usually between 80 and 90 per cent. magnesia, the remainder being oxides of silicon, iron and lime. In typical Austrian magnesite oxide of iron forms the chief impurity, in Greek magnesite, lime and silica, in Canadian magnesite, lime, and in Californian magnesite silica. The effect of these impurities can be easily seen on examining a microsection of a magnesite brick.[61] If the impurity be mainly iron oxide, the brick consists mainly of a network of polygonal periclase crystals, with much smaller included crystals of magnesioferrite ($MgFe_2O_4$).[57] On the other hand, if lime and silica be the main impurities, the brick consists of a clear base, sometimes glassy, sometimes crystalline, in which are set rounded crystals of periclase. In the former the periclase is usually dark in colour and has a well-developed cleavage; this may be due to the presence, in solid solution, of a certain amount of iron oxide. (Pl. xx., Fig. 5.) The difference between the two types of structure is much more obvious when the section is examined between crossed nicols; the one type then appears to be almost wholly isotropic while the other often shows the doubly refracting matrix. (Plate xx., Fig. 4.)

The nature of the crystalline matrix has given rise to some discussion.[58] Such minerals as forsherite and monticellite have been definitely recognised, but some other crystalline material which has been noted has not yet been identified with any degree of certainty. In many cases the material of the matrix is in a molten condition when the brick is in use. A brick containing monticellite as the matrix will, if heated to 1600° C. and quenched, show a glassy mesostasis containing unaltered crystals of periclase.

The examination of a series of specimens of magnesite calcined

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(1.) (2.)

(3.) (4.)

(5.) (6.)

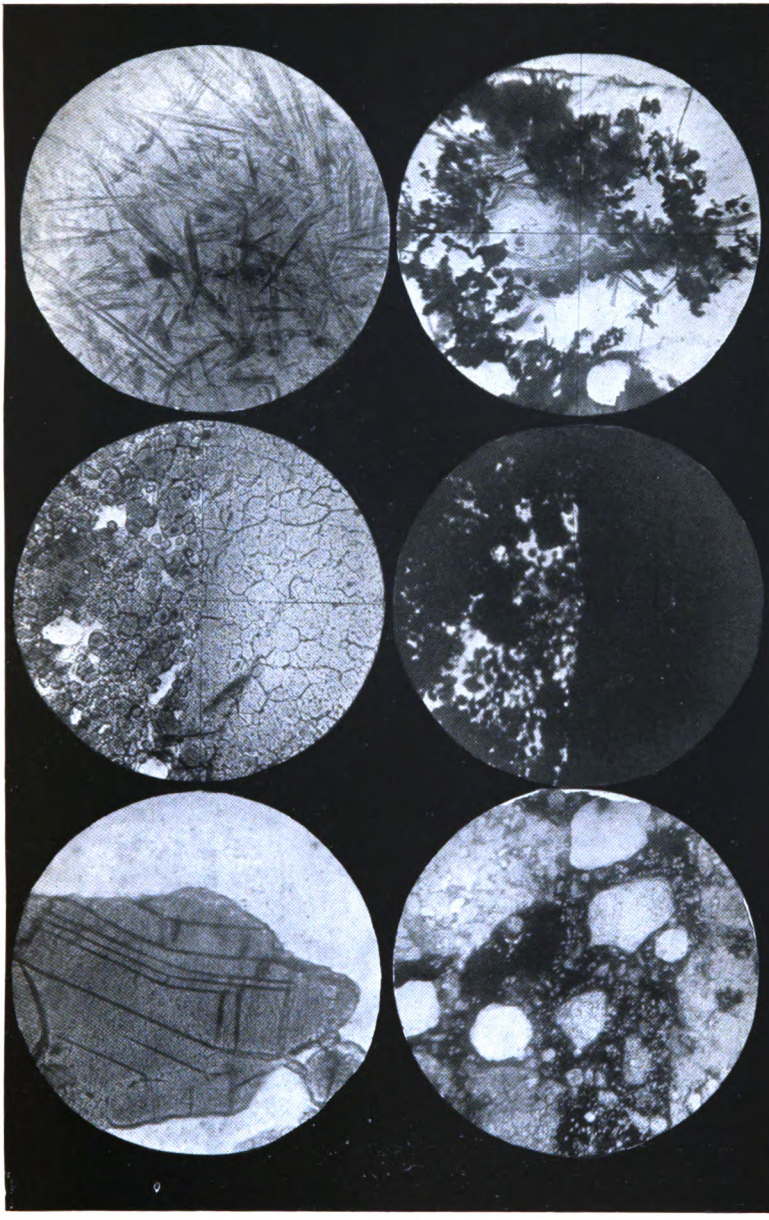

Fig. 1.—Acicular crystals of sillimanite in firebrick heated to 1700° C. × 40
Fig. 2.—Section of zinc retort, showing clear glass with lath-shaped crystals of zinc silicate; dark material is mainly magnetite × 120
Fig. 3.—Magnesite brick. Right half shows network of periclase with "spots" of magnesio-ferrite. Left half shows rounded periclase grains in clear matrix. × 40
Fig. 4.—Same between crossed nicols. Right half is isotropic while left shows doubly refracting matrix. × 40
Fig. 5.—Crystals of periclase showing cleavage. × 500
Fig. 6.—Section of silica brick showing penetration of flue dust. Latter is confined to matrix, the "grog" fragments being unattached. × 45

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for different periods gives some indication as to the cause of the known change of specific gravity which calcined magnesite undergoes on further heating. The gradual transformation of the amorphous magnesia to the crystalline form can be traced. This seems to be accelerated by the presence of the impurities, which probably dissolve the amorphous material and reprecipitate it as the crystalline form. On further heating the periclase continue to grow in size[61] by the coalescence of the original minute ones, and this is accompanied by an increase in density of the mass. There is no foundation whatever for the statement that magnesia exists in several polymorphic forms; there is only one crystalline form, periclase, and the only other forms are amorphous.[59]

Lightly calcined magnesia consists of the amorphous variety; dead-burned magnesia is mainly crystalline, though the crystals are very fine-grained, while bricks which have been in use for prolonged periods may have comparatively large crystals. Where the material has been in contact with iron, as in the hearth of a "basic" furnace, iron oxide may react with the magnesia and form a dense opaque mass which is largely magnesioferrite. Comparatively few investigations have been made regarding used magnesite bricks.

With regard to magnesite refractories, there is a large field for investigation with the aid of the microscope. A systematic examination of raw magnesites, of the calcined material and of the bricks made therefrom, would throw much light on the influence of the various impurities such as serpentine, &c. There is little doubt that the original form of these impurities, as well as their chemical composition, affects the properties of the brick.

Zirconite Refractories.—So far as the writer is aware, nothing has been published concerning the microstructure of zirconite refractories. Microsections of such bricks in the unused condition show comparatively little unless they are very thin. The brick seems to consist of a dark, apparently amorphous matrix in which are set numerous minute crystals with a high double refraction and refractive index. The habit, together with the optical properties, suggests *baddeleyite*. A brick which had been in use for a considerable period in a glass furnace had a very similar structure. A mass of zirconia which had been fused to an apparently glassy mass showed on micro-examination similar crystals of very small dimensions set in an isotropic matrix. So

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far, no results of any practical value have resulted from the application of microscopical methods to materials composed of zirconia.

Conclusion.—In addition to the summary given above, petrographic methods have been applied to various other types of refractory materials, but as these have been described elsewhere, they need not be considered here. For example, Boswell, in his various memoirs on sands for moulding and other purposes, has largely used the methods of petrography. So far as the materials mentioned above are concerned, there is still scope for much work. Thus, despite the researches of Hutchings, Gregory, and others, very little petrographic information is available concerning the fireclays of this country, while of the influence of the impurities on the firebricks practically nothing is known. It is to be hoped that research on such subjects will be carried out in the near future.

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PROCEEDINGS OF THE GEOLOGICAL SOCIETY OF GLASGOW.

SESSION 1917-1919.

(Sixtieth and Sixty-First Session).

SOCIETY'S ROOMS, 207 BATH STREET, GLASGOW, 8TH NOVEMBER, 1917.

The second meeting of the sixtieth Session of the Geological Society of Glasgow was held here this evening—Rev. C. A. HALL in the chair.

The Minutes of the previous meeting were read and adopted.

Miss G. L. Keay was elected a Lady Member; Miss Pearson, an Associate Member; and Messrs. A. Wallace, 1 Dundas Cottages, Castlecary, and C. R. Somerville, 26 Tassie Street, Shawlands, Ordinary Members.

The following reports for Session 1916-17 were submitted:—

(*a*) Council Report by Mr. P. Macnair and Dr. A. Scott, *Joint Hon. Secretaries.*

(*b*) Financial Report by Mr. D. Smith, *Hon. Treasurer.*

(*c*) Library Report by Mr. Wm. Sinclair, *Hon. Librarian.*

On the proposal of Messrs. Hall and Conacher, these reports were unanimously adopted.

The following office-bearers were elected:—

As President—Dr. R. Kidston, F.R.S., proposed by Professor J. W. Gregory, Mr. C. R. Cowie and Mr. H. R. J. Conacher.

As Vice-President (for Three Years)—Mr. Peter Macnair, proposed by Mr. G. W. Tyrrell and Dr. A. Scott.

As Hon. Secretaries (for Three Years)—Mr. A. Scott, M.A., D.Sc., and Mr. D. B. Duncanson, B.Sc., proposed by Mr. H. R. J. Conacher and Mr. J. L. Begg.

As Hon. Treasurer (for Three Years)—Mr. James L. Begg, proposed by Mr. D. B. Duncanson and Mr. D. Smith.

As Hon. Librarian (for Three Years)—Mr. Wm. Sinclair, proposed by Mr. Maclean and Mr. G. W. Tyrrell.

As Members of Council (for Three Years)—Mr. M. MacGregor, M.A., B.Sc., proposed by Dr. A. Scott and Mr. D. N. M'Arthur; Mr. J. G. Roberts, proposed by Mr. G. W. Tyrrell and Mr. D. B. Duncanson; Mr. James Hamilton, proposed by Mr. H. R. J. Conacher and Dr. A. Scott; Mr. H. Priestley, proposed by Rev. C. A. Hall and Mr. D. Smith.

Mr. CONACHER exhibited specimens of albertite from the West Lothian shale field.

Mr. G. W. TYRRELL read a paper, entitled "New Views of the Origin of the Old Red Sandstone," and Mr. MACNAIR a paper on "The Marine Origin of the Old Red Sandstone."

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SOCIETY'S ROOMS, 207 BATH STREET, GLASGOW, 13TH DECEMBER, 1917.

The third meeting of the sixtieth Session of the Geological Society of Glasgow was held here this evening—Mr. G. W. TYRRELL in the chair.

The Minutes of the previous meeting were read and adopted.

Mr. G. W. TYRRELL exhibited a number of fossils from the "Christie's Collection."

Dr. A. SCOTT delivered an address, entitled "Some Technical Applications of Petrology."

The discussion was sustained by Messrs. Donald, Tyrrell and Roberts.

CHARLES A. HALL.

SOCIETY'S ROOMS, 207 BATH STREET, GLASGOW, 10TH JANUARY, 1918.

The fourth meeting of the sixtieth Session of the Geological Society of Glasgow was held here this evening—Rev. C. A. HALL in the chair.

The Minutes of the previous meeting were read and adopted.

Mr. James Main, Bonnybridge, and Mr. John Taylor, Castlecary, by Bonnybridge, proposed by Messrs. Macnair and Scott, were elected Ordinary Members of the Society.

Dr. R. KIDSTON, F.R.S., delivered the presidential address on "An Old Red Sandstone Plant: its Structure and Mode of Occurrence."

Dr. KIDSTON first referred to the discovery of the chert bed, containing plant remains at Muir of Rhynie, by Dr. W. Mackie of Elgin. So far, two vascular plants have been found in the deposit. These are Rhynia Gwynne-Vaughani and Asteroxylon Mackiei, but only the former has been examined in detail. The chert zone was originally formed of a series of peat beds, which, through periodic inundation, have been intercalated with thin layers of sand. In some cases, the plants can be seen growing vertically from the ancient land surface. In many places the silicified peat is made up almost entirely of the stems and rhizomes of Rhynia.

The plant, which is found with its structure excellently preserved, formed a pure growth with erect cylindrical stem, 8 inches high and 1 to 6 mm. in diameter. It had neither leaves nor roots, but was attached to the peaty soil by numerous rhizoids branching from rhizomes which occasionally become aerial. The stem was dichotomously branched, and bore small hemispherical projections. In both the rhizomes and stems the epidermis, outer cortex, inner cortex and stele can be distinguished. The narrow outer cortex in the aerial stems had the character of a hypoderma, while numerous intercellular spaces in the inner cortex occurred, apparently in relation to the stomata. The stele was cylindrical and composed of a solid mass of tracheides, the protoxylem and metaxylem being indistinguishable. The phloem of thin walled, elongated cells surrounded the xylem. The sporangium, which was large and cylindrical, contained numerous spores, all of one kind.

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This is the most ancient land plant whose structure is at all fully known. With regard to its position in the vegetable kingdom it is allied to Psilophyton princeps, the two making up the only known genera of the class; Psilophytales, which belongs to the Pteridophyta, and which is characterised by the sporangia being borne at the end of certain branches of the stem without any apparent relation to leaves.

PETER MACNAIR.

SOCIETY'S ROOMS, 207 BATH STREET, GLASGOW, 14TH FEBRUARY, 1918.

The fifth meeting of the sixtieth Session of the Geological Society of Glasgow was held here this evening—Mr. P. MACNAIR in the chair.

The Minutes of the previous meeting were read and adopted.

Mr. Norman Stein, Castlecary, proposed by Dr. Scott and Mr. Macnair, and Mr. T. S. Jones, Calderbank, proposed by Mr. Duncanson and Dr. Scott, were elected Ordinary Members of the Society.

Mr. G. W. TYRRELL showed a remarkable specimen of sandstone, with ripple-marking, rain-puttings and reptilian tracks from the Old Red Sandstone of Carrick, Ayrshire.

Mr. P. MACNAIR exhibited specimens of "Derbya sp." collected from the Roman cement, Castlecary, by Mr. Wallace.

Mr. J. L. BEGG exhibited "Productus proboscidens" from the Isle of Man.

Mr. H. R. J. CONACHER read a paper, entitled "Notes on the Micrology of Coal."

At the outset it was stated this work was incomplete, but as it was unlikely to be resumed for some considerable time, the results were brought together in the hope that they may be of some use to others.

Micro examination, which nearly a century ago had provided the first internal evidence as to the vegetable origin of coal, has been much neglected during the last twenty years, probably owing to the difficulties in producing satisfactory sections of coal.

The earliest plant structures to be recognised in coal were spores, shown by Bennie and Kidston, to be those of vascular cryptogams, and these often occur as closely packed masses of mega and microspores. Tasmanite is made up of the spores of an unknown plant, mixed with sand.

The two types of material in bright coal are—(*a*) jet-like layers with conchoidal fracture, and showing in thin section vegetable cell structure, and (*b*) dull cannel-like portions, enveloping the former and consisting of minute debris of spore coats, plant tissue, &c. Charcoal, often with an altered cell structure, occurs along with the above types.

In the cannels are varying degrees of elimination of all recognisable plant tissues, while there is evidence of open water in the presence of fish scales and teeth, and even marine shells. Allied to the cannels are the Boghead coals or torbanites, and the "rhums" of Fife, and the hornie shales of Lanarkshire and Ayrshire.

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The formation of coal seems to be the result of the operation of numerous variable factors—the nature of the vegetation, conditions of accumulation, and the biological and geological processes which act on the vegetable deposits.

PETER MACNAIR.

SOCIETY'S ROOMS, 207 BATH STREET, GLASGOW, 14TH MARCH, 1918.

The sixth meeting of the sixtieth Session of the Geological Society of Glasgow was held here this evening—Mr. G. W. MACNAIR in the chair.

The Minutes of the previous meeting were read and adopted.

Mr. ROBERTS read a paper on "Clays," dealing especially with their industrial uses. The casting of clay slip into moulds was demonstrated, and photographs of complicated apparatus cast in this way were exhibited. Under pressure, castings up to five inches in thickness can be made. The effect of different electrolytes in varying amounts on the viscosity of clay slip was discussed, and the results shown graphically. The separation of impurities in clays containing electrolytes by the application of the electric current was also shown, the pure clay from the slip being deposited on the negative hole in a firm plastic condition.

In the discussion Mr. D. N. M'Arthur referred to the action of calcium hydroxide on clay, and the importance of this in agriculture. Messrs. Cowie, M'Gregor and Macnair also took part in the discussion.

Mr. STARK read a paper, entitled "Geological Notes on Burma." The geology of Burma is especially interesting on account of the light it throws on the origin of the Scottish Old Red Sandstone. The basin of the Irrawady lies in soft new rocks, which are so rapidly eroded by the river that during the rainy season 340 million tons of yellow clay is removed and spread out in a thickness of 0·1″ per annum round the river mouth. Twenty-five miles from the shore the depth is not twenty fathoms, so that we have here a great submarine plain of deposition. In this delta, which is about half the area of Scotland, numerous changes in the river channels, accompanied by the formation of banks and islands, occur in the rainy season.

Most of the rivers flow in synclives in Miocene and Pliocene rocks, the latter being 4000 feet thick, and containing vertebrate fossils similar to those of the Siwalik hills. Much silicified wood occurs, but marine organisms are absent. During the rainy season large temporary lakes form with the deposition of coarse boulder beds, twenty miles wide and 200 miles long, and closely resembling the Old Red Sandstone conglomerates.

The Burmese oil wells were also described, and it was pointed out that the oil is found in the anticlives, and water in the synclives. Numerous interesting lantern slides were shown.

Mr. C. R. COWIE contributed some additional facts relating to the oil wells and the underground water.

PETER MACNAIR.

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SOCIETY'S ROOMS, 207 BATH STREET, GLASGOW, 11TH APRIL, 1918.

The seventh meeting of the sixtieth Session of the Geological Society of Glasgow was held here this evening—Mr. P. MACNAIR in the chair.

The Minutes of the previous meeting were read and adopted.

The following were elected Honorary Members:—

Non-Resident—Prof. A. Lacroix, Paris; Prof. R. A. Daly, Harvard, Cambridge, Mass., U.S.A., and Prof. G. A. J. Cole, Royal College of Science, Dublin; all proposed by Dr. Scott and Mr. G. W. Tyrrell.

Resident—Dr. J. S. Flett, H.M. Geol. Survey, Edinburgh, proposed by Messrs. Macnair and Duncanson, and Mr. J. S. Macconachie, H.M. Geol. Survey, Edinburgh, proposed by Messrs. Begg and Macnair.

Mr. P. MACNAIR exhibited specimens and sections of "Rhynia Gwynne-Vaughani," which had already been described to the Society by Dr. Kidston.

Mr. G. W. TYRRELL read a paper on "The Geology of the Heads of Ayr."

G. W. TYRRELL.

SOCIETY'S ROOMS, 207 BATH STREET, GLASGOW, 9TH MAY, 1918.

The eighth meeting of the sixtieth Session of the Geological Society of Glasgow was held here this evening—Mr. G. W. Tyrrell in the chair.

The Minutes of previous meeting were read and adopted.

Mr. A. Milligan, c/o Martin, 8 Steven Drive, Linthouse, was elected an Ordinary Member.

Mr. P. MACNAIR read a paper on "The Fauna of the Blackbyre Limestone."

G. W. TYRRELL.

SOCIETY'S ROOMS, 207 BATH STREET, GLASGOW, 11TH OCTOBER, 1918.

The opening meeting of the sixty-first Session of the Geological Society of Glasgow was held here this evening—Mr. G. W. TYRRELL in the chair.

The Minutes of the previous meeting were read and adopted.

Mr. W. H. Coleman, 1 Athole Gardens, Newlands, and Dr. David Ellis, Birch Tor, Milngavie, were elected Ordinary Members.

Mr. JAMES STARK then read the following obituary on the late Mr. John Renwick:—

"The Geological Society of Glasgow has lost, since its last meeting, one of its oldest and most highly esteemed members in the person of Mr. John Renwick, who died on 23rd July, 1918, at the age of sixty-seven.

Mr. Renwick became a member of the Society in 1874, forty-four years ago. Joining at twenty-three years of age, he kept up his youthful enthusiasm to the last. For many years he was a member of Council and Convener of the Excursion Committee, and filled for a term the office of Vice-President. Early last year he was elected an Honorary Member

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In all his work for the Society, what his hand found to do he did with his might. Many enjoyable and instructive excursions were arranged by him, a good number of which he personally conducted. One of the first excursions which I had the pleasure of attending was for the purpose of illustrating papers by the late Mr. Dougald Bell and himself on the Glen Fruin Moraine, in which Mr. Bell maintained that it had been laid down by a glacier coming down Glen Fruin, and Mr. Renwick by that coming down Loch Lomond. There is now no doubt that Mr. Renwick was in the right. In another paper Mr. Renwick maintained the view that the Auld Wives' Lifts assumed their present form from purely natural causes, and I shall be surprised if he is not found to have been in the right there also. Mr. Renwick was also a member of the Natural History Society, to which he rendered similar valuable services. Joining in 1879 he was its Treasurer for thirty-two years, and contributed many papers and exhibits, mainly on the various species of trees of the west of Scotland. These papers were accompanied by tables of the dimensions of the more notable ones: indeed, he seldom went abroad without his tape line in his pocket. He was also an esteemed correspondent with many distinguished exponents of Natural History. But it will be as a man and a friend that Mr. Renwick will best be remembered by those who had the privilege of knowing him. 'An honest man is the noblest work of God,' says the poet, and that was John Renwick. 'Tender and True' is the motto of an ancient Scottish noble house, and it might well have been his, for such he was. He was endowed with a full share of pawkie humour. Even in the long and painful illness, which he knew could only end in death, his smile and cheerful humour never failed. For the last two years of his life he was hardly ever out of doors, and very little out of bed, which must have been a sad trial to such a lover of Nature as he.

To his wife, who tended him in his weakness and pain for over three years with unremitting care, our heartfelt sympathy goes out in her great loss. To himself, his passing must have been a blessed release."

Mr. STARK proposed that a letter of condolence be sent by the Secretary to Mrs. Renwick.

Mr. ROBERT CAMPBELL, D.Sc., Edinburgh University, then delivered an address on the "Rocks of the Highland Border Series." This group of rocks can be traced as an interrupted belt from Stonehaven to Arran, and consists of cherts or jaspers, graphitic shales and various igneous rocks often highly altered. Some of the beds of this marginal belt are so little altered that it was expected that fossils might be found in them, and so give light on their age, and in 1911 Dr. Campbell recorded brachiopods and crustaceans with worm tubes in shales and jaspers, associated with spilitic lavas at Stonehaven, south of the Boundary Fault. In 1912 similar fossils were found by Dr. John near Aberfoyle, on the north-west side of the great Fault. These discoveries gave evidence for assessing Upper Cambrian or Lower Ordovician age of the black shales and cherts. The Border rocks divide into (*a*) a series of black shales, cherts and mudstone, with igneous

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rocks, and an unconformable series of grits and shales with calcareous bands. The upper series have been named Margie by Mr. Barrow. This group has a remarkable breccia at its base, containing fragments of vesicular lava. Dr. Campbell gave some details as to the structure of the rocks, and showed a large number of photomicrographs. The spilite lavas are all highly altered, and in some cases consist of secondary minerals—chlorite quartz, carbonates, micas, epidote and haematite. The cherts are very rich in Radiolaria, and evidently represent oozes which accumulated in clear water. In the Margie series, as has been said, a basement breccia well seen at Clashbeg Wood is characterised by large fragments of cherty shales sometimes as large as 3 feet by 1½ feet, and containing vesicular palagonite quartz and cherty shale. The limestone of this series is bluish and crystalline. Its chief interest lies in its proving to be in places highly fossiliferous.

Mr. Macnair and Mr. G. W. Tyrrell made some remarks on the lecture.

The Chairman drew attention to the change in the housing of the Society's periodicals, which have all been transferred to the Baillie's Institution, West Regent Street.

CHARLES A. HALL.

SOCIETY'S ROOMS, 207 BATH STREET, GLASGOW, 14TH NOVEMBER, 1918.

The second Meeting of the sixty-first Session of the Geological Society of Glasgow was held here this evening—Rev. CHARLES HALL in the chair.

The Minutes of the previous meeting having been read and adopted, the following reports were read :—

(*a*) Council Report by Dr. A. Scott and Mr. D. B. Duncanson.

(*b*) Financial Report by Mr. J. L. Begg, *Hon. Treasurer.*

(*c*) Library Report by Mr. Wm. Sinclair, *Hon. Librarian.*

Mr. CHARLES COWIE moved the adoption of the Council's Report; Mr. JAMES STEEL moved the adoption of the Reports of Finance and Library, and this was agreed to.

In the report of Finance Mr. Begg referred to the handsome donation of £17 by Mr. Charles R. Cowie to defray the cost of the plates in the *Transactions*, and it was considered that, with the balance in hand of the Society, might consider the publication of some of the papers to be read this session.

In reference to the remarks on attendance at the meetings in the Report of Council Dr. Samuel Sloan asked if nothing could be done to remedy this, and suggested that readers of papers might perhaps, by a slight introduction or modification of treatment, make more appeals to the non-specialist members. Mr. C. R. Cowie, replying on behalf the Council, assured Dr. Sloan that what he had said would be seriously considered by them.

The following new office-bearers were elected :—

Vice-President (for Three Years)—Dr. W. R. Smellie, proposed by Mr. D. B. Duncanson and Mr. D. W. MacArthur.

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Members of Council (for Three Years)—Mr. C. M. Leitch, B.Sc., pro posed by Dr. Scott and Mr. J. G. Roberts; Mr. James Stark, proposed b Dr. Scott and Mr. G. W. Tyrrell; Mr. R. W. Drow, M.Inst. C.E., proposed by Mr. J. L. Begg and Mr. D. B. Duncanson; Mr. James Neilson, proposed by Mr. G. W. Tyrrell and Mr. J. L. Begg.

Mr. G. W. Tyrrell was appointed by Council—Joint Secretary—in plac of Dr. Alexander Scott, whose new duties as head of the Refractories Department at Stoke-on-Trent render it impossible for him to continue in office.

Dr. David Ellis then read a paper, entitled "Fossil Fungi from the Lower Coal Measures." In his address the author described peronosporites antiquarius from the slides made by Williamson, which are preserved in the British Museum. This was used for purposes of comparison with Renault's palacomyces gracilis, first recorded by Renault from the French carboniferous rocks. The lecturer, by means of photomicrographs and drawings, showed the affinities of this organism to the genus peronosporites, and proposed to rename the fungus peronosporites gracilis. The best specimens were obtained from a stem of lepidodendron aculeatum from Upper Foot Mine, Littleborough, and evidence was discussed for the parasitic nature of the organism. Globular swellings on the hyphae were described by Williamson and Worthington Smith as oogonia, but Dr. Ellis regards these rather as intercalary sporangia, a frequent phenomena in modern fungi. A new fungus, palacomyces bacilloides, Ellis discovered in the parenchyma of the leaf bases of a lepidodendron was next described, whose chief characteristic is the giving off at intervals of bacteria-like threads about 1 u. in thickness, and some evidence was produced to show that these threads could grow and divide after contact with the hypha had been broken. Dr. Ellis suggests that we may here have a case of pleomorphic change from fungus to bacteria.

G. W. TYRRELL.

Society's Rooms, 207 Bath Street, Glasgow, 12th December, 1918.

The third monthly meeting of the Society was held here this evening—Mr. G. W. Tyrrell in the chair.

The Minutes of last meeting having been read and adopted, the Chairman intimated the bequest by the late John Orr of £100 to the funds of the Society.

Mr. Neilson gave from memory a few reminiscences of Mr. Orr. He joined the Society in 1869, and although keenly interested in the work of the Society, took no active part in papers or discussions.

Mr. Macnair said that Mr. Orr was the third oldest member, Sir Archibald Geikie and John Smith, who are still with us, preceding him.

He was interested in botany and made a good collection of fossil plants, which has been acquired for the Kelvingrove Museum.

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Mr. JAMES STEEL gave notice of motion that £10 (ten pounds) be devoted to the purposes of the Library.

Mr. JAMES STARK then read a paper on "The Glacial Origin of the Auld Wives' Lifts," and a short paper on "The Whangie."

Messrs. Dron, Macnair, Neilson and Tyrrell took part in the discussion, and Mr. Stark was warmly thanked for his interesting paper.

Mr. ROBERT DUNLOP then read a paper by Mr. James Wright on "The Carboniferous Crinoids of Fife," with notes of localities and provisional lists of species.

PETER MACNAIR.

SOCIETY'S ROOMS, 207 BATH STREET, GLASGOW, 9TH JANUARY, 1919.

The fourth meeting of the sixty-first Session of the Geological Society of Glasgow was held here this evening—Mr. PETER MACNAIR in the chair.

The Minutes of last meeting were read and adopted.

Mr. JAMES STEEL moved that £10 be devoted to the Library, and this was seconded by Mr. James Stark.

Mr. John M'Gill was nominated a member of the Society.

The PRESIDENT (Dr. Robert Kidston, F.R.S.), then gave an address on "Further Notes on Rhynia Gwynne-Vaughani," with descriptions of Rhynia Major and Hornea Lignieri from the Rhynia Chert band, Aberdeenshire.

By a series of beautiful photomicrographs Dr. Kidston showed how much further detail had been made out of the structure of Rhynia since his last lecture, and how this had led to the discovery of a second species, Rhynia Major, remarkable for the size of the sporangium in comparison with that of Gwynne-Vaughani. The address concluded with a description of Hornea Lignieri.

R. W. DRON.

SOCIETY'S ROOMS, 207 BATH STREET, GLASGOW, 13TH FEBRUARY, 1919.

The fifth meeting of the sixty-first Session of the Geological Society of Glasgow was held here this evening—Mr. R. W. DRON in the chair.

The Minutes of last meeting were read and adopted.

Mr. G. W. TYRRELL delivered a lecture, entitled "Modern Views on Volcanoes."

The older idea of volcanic activity was that steam escaping from magmatic solution was the chief agent in bringing about the ascent of the lava and the accompanying explosions. The essential features of volcanoes were the escape of lava and gases from a pipe or fissure. The gases observed, which differ in different volcanoes, were steam, hydrogen, methane, sulphur, sulphur dioxide, hydrogen sulphide, chlorine, boric acid and carbon dioxide.

In attempting to explain how volcanic vents are opened one had to consider the place of eruption and its persistence in one place, also its

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independence of neighbouring vents. Mr. Tyrrell then discussed the hypotheses put forward by Daly, Brün, Day and Shepherd. Prof. Daly's great contribution is the linking-on of volcanic activity with the vastly greater subterranean activity, and developed the gas-fluxing hypotheses of volcanic vents. Dr. Brün advocated the view that volcanic activity is essentially anhydrous; but this was disproved by Drs. Day and Shepherd, who actually collected the gases from the lava lake at Kilauea, and demonstrated the presence of water, although in comparatively small quantity. The other view of volcanic mechanism was that it was comparable to a steam engine; the more modern view is that the analogy is more with a gas engine actuated by internal combustion.

G. W. TYRRELL.

SOCIETY'S ROOMS, 207 BATH STREET, GLASGOW, 13TH MARCH, 1919.

The sixth meeting of the sixty-first Session of the Geological Society of Glasgow was held here this evening—Mr. G. W. TYRRELL (Vice-President), in the chair.

After the Minutes of last meeting had been read and adopted, Mr. R. W. DRON, F.R.S.E., delivered a lecture on "The Iron Ore Resources of Scotland." Mr. Herdsman spoke as to the meagreness of Scotland's ores of iron, while Mr. Dixon stated that the problem of cheap and facile transport was not a matter of appliances, but was purely a labour question.

M. HARRY CONACHER then read a highly-interesting paper on "The Conditions of Accumulation of the Oil Shale Series." Exhibiting a collection of bores, Mr. Conacher showed that there was strong evidence of a mud surface being exposed long enough to the air to produce deep drying cracks. These cracks were then subsequently filled with sand, probably wind borne, forming minute sandstone dykes. By pressure this material had become consolidated and the dykes distorted. Where fine mud had been covered with sand Mr. Conacher suggested that water action was ruled out, because a current that could carry such sand would wash out the fine mud. In the discussion it was suggested that a pellicle of bacteria covering the mud might resist the action of the water sufficiently to account for the definite demarcation surface. Mr. Tyrrell pointed to the value of the evidence which Mr. Conacher had brought forward as to the light such "fossil landscapes" shed on the conditions of deposit of rocks.

G. W. TYRRELL.

SOCIETY'S ROOMS, 207 BATH STREET, GLASGOW, 10TH APRIL, 1919.

The seventh meeting of the sixty-first Session of the Geological Society of Glasgow was held here this evening—Mr. G. W. TYRRELL in the chair.

The Minutes of last meeting were read and adopted.

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Mr. James Frew, 180 Hope Street, proposed and seconded by Mr. R. W. Dron and D. B. Duncanson, was admitted a member of the Society.

A letter from Mr. Conacher was read regarding a communication from Mr. Black, a corresponding member of the Society. Mr. Black, after some research in the Paris Library, has succeeded in tracing the date of publication of Ami Boué's Essai sur Geologie d'Eccosse as 1820.

Mr. G. W. Wilson, H.M. Survey, then read a paper on "The Millstone Grit Fireclays of North Ayrshire." These beds, when discovered by Mr. John Smith, were described by him as Volcanic Guffs, but the discovery by Mr. Douglas of the highly refractory nature of the Monkcastle clay led to a reconsideration of the whole deposit of the Bauxitic clays. The outcrop has been traced from Saltcoats to Kilmarnock, and deposits of a similar nature occur at Mauchline, Sanquhar, Stranraer, and in Arran. The material is very black, hard and non-plastic, and contains many oolites. Its Al_2O_3 content runs from 26 to 50 per cent. When exposed to high temperatures rosettes of sillimanite, coloured blue possibly by titanium, are formed. This, as well as the oolitic structure, was demonstrated by a series of photomicrographs.

With regard to the origin of those deposits the lecturer put forward the hypothesis of tropical conditions acting on the beds of lava, on which perhaps a hummocky surface permitted the formation of extensive pools of stagnant shallow water, with abundance of decaying vegetable matter giving rise to CO. CO_2 CH_4 gases. The gases, by reducing action, might render soluble the iron and alumina, and lead to their segregation in different parts of the deposit. The oolitic structure of the alumina particles seemed to suggest that this mineral might, under certain circumstances, pass into solution. The deposits elsewhere are regarded by Mr. Wilson as due to redistribution.

Mr. Tyrrell asked if any evidence had been noticed as to volume change, but Mr. Wilson said he had none, as the rock is non-porous. Mr. Macnair also took part in the discussion.

A hearty vote of thanks was accorded Mr. Wilson.

G. W. TYRRELL.

Society's Rooms, 207 Bath Street, Glasgow, 8th May, 1919.

The eighth meeting of the sixty-first Session of the Geological Society of Glasgow was held here this evening—Mr. G. W. Tyrrell in the chair.

The Minutes of the seventh meeting having been read and adopted, Mr. H. R. J. Conacher read a paper on the "Micrology of the Oil Shale Series." It was pointed out that the most striking features of the sandstones was the angularity of the grains, and the occasional presence of fresh and angular particles of volcanic rock. The cement of these sandstones is generally calcareous, and frequently constitutes a very large percentage of the whole rock as seen in thin section.

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Some clue is given as to the age of this cement by its relation to the oil which sometimes saturates the rock, and the age of which can be fixed by that of the igneous rock which distilled it from the shales. Occasionally the sandstone occurs as very thin ribs in blaes, or even as a single layer of sand grains along the bedding plane, as if strewn across the wet surface of mud by wind. The sandstones sometimes pass by imperceptible gradations into dense hard oolites. When a nucleus can be detected in the oolitic grain it is generally found to be a fragment of plant tissue still showing the structure, but signs of animal life are rare, except carbonised worm tubes, although an oolitic limestone may pass either upwards or downwards into an entomostracan seam. Spirorbis limestones occasionally occur, and the frequent ostracod beds present numerous interesting features under the microscope. Not the least interesting part of Mr. Conacher's notes was the very fine series of some fifty micro-sections by which it was illustrated. These were exhibited with the Society's micro-projector, and were demonstrated by Mr. Conacher. Mr. Conacher was complimented for the skill and industry in which his researches on the oil shales and their origin were being prosecuted, and a hearty vote of thanks was awarded him.

Mr. Colin M. Leitch, B.Sc., then read a short paper on an "Ultra Basic Intrusion in South Bute." This intrusion occurs 200 yards south of Hawk's Nib, and is intruded as a sill dipping south into the calciferous sandstone sediments. The intrusion proper is a microporphyritic olivine basalt of the Hillhouse type. There has been a gravity separation of the xenoliths, the heavier of which are found near the northern or lower face, while the southern portion is free from them. They are purely "Cognate" xenoliths, and by their texture and composition are seen to be representatives of a long suite of ultra basic plutonic rocks, which includes the single mineral rocks, dunite, pyroxenite and anorthosite, and many combinations of these minerals giving rise to peridotites and gabbros. The source of the xenoliths seems to have been an uncovered mass of plutonic rock which the ascending basalt traversed. This paper also was illustrated by micro-sections shown under polarised light by the micro-projector, and Mr. Leitch was complimented by Mr. Tyrrell on his first paper to the Society, and was accorded a vote of thanks for his interesting paper.

G. W. TYRRELL.

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ABSTRACT

OF THE

TREASURER'S ACCOUNTS.

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ABSTRACT OF THE TREASURER'S ACCOUNTS FOR THE YEAR ENDED 30TH SEPTEMBER, 1918.

CASH ACCOUNT.

RECEIPTS.

To Balance at 30th Sept., 1917:—			
Cash in Bank on Deposit Receipt, ...	£30 0 0		
Do. in Hon. Treasurer's Hands, ...	7 10 11		
		£37 10 11	
,, Subscriptions:—			
Ordinary (including 9 new Members)—122 at 10/, ...	£61 0 0		
Do. (Lady Members)—6 at 7/6, ..	2 5 0		
Do. Arrears—6 at 10/, ...	3 0 0		
Do. do. 1 at 7/6, ...	0 7 6		
Associate Member—1 at 2/6, ...	0 2 6		
Life Members—3 at £5 5/, ...	15 15 0		
		82 10 0	
,, Interest on Funds (*less* Tax), ...	.. ..	6 15 0	
,, Do. Mr. Cowie's Donation (*less* Tax),	.. ..	3 15 0	
,, Deposit Receipt Interest, ...	.. ..	1 15 10	
,, Sale of Books and Publications, ...	.. ..	6 3 6	
,, Voluntary Subscriptions towards increased cost of *Transactions*, Vol. XVI., Par. II., ...	.. ..	18 19 6	
			£157 9 9

EXPENDITURE.

By *Transactions*:—				
Printing and Publishing Vol. XVI., Par II. (1916-17), including cost of illustrations and Authors' Copies of Papers, ...		£133 6 2		
Postages and Outlays, ...		2 6 6		
		£135 12 8		
,, *Less*:—				
Donation from Dr. Gregory for Publication of "Presidential Address,"	£15 0 8			
Donation from Mr. C. R. Cowie,	17 13 4			
Donation from Publisher, ..	10 10 0			
Glasgow University for Copies of Papers, ...	8 12 1			
Authors for extra Copies, ..	20 3 3			
		71 19 4		
			£63 13 4	
,, Library:—				
Books and Magazines, ...			1 11 6	
,, Subscription to Marine Biological Association, 1918, ..			1 1 0	
,, ,, to Palæontographical Society, 1918, ...			1 1 0	
,, ,, to Natural History Society, for use of Lantern, 1917-18, ...			1 1 0	
,, Mr. Cowie's Donation:—				
Glasgow University, Interest to Martinmas, 1917, ...		£1 17 6		
Royal Technical College, Interest to Martinmas, 1917, ...		1 17 6		
			3 15 0	
,, Administration:—				
Printing and Postage of Cards and Advertising, ...		£15 3 2		
Printing Lists of Members and Copies, ..		3 10 4		
Rent, Insurance, and Attendance, ...		11 19 0		
Hon. Secretaries' and Hon. Treasurer's Postages, ...		2 17 10		
			33 10 4	
,, Cash in Bank, ...		£38 4 6		
,, Do. in Hon. Treasurer's Hands, ..	£11 2 1			
,, Accrued Interest on Mr. Cowie's Donation, ...	2 10 0			
		13 12 1		
			51 16 7	
			£157 9 9	

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LIFE SUBSCRIPTION ACCOUNT.

Sept. 30, 1918.—To Balance to Credit,	£219 5 0	Sept. 30, 1917.—By Balance from last Account,	£203 10 0
		Sept. 30, 1918.— ,, New Subscriptions,	15 15 0
	£219 5 0		£219 5 0

C. R. COWIE'S PRIZE FUND.

Sept. 30, 1918.—To Glasgow University, one-half of Interest to Martinmas, 1918,	£1 17 6	Sept. 30, 1917.—By Balance from last Account,	£102 10 0
,, The Royal Technical College, Glasgow, one-half of Interest to do.,	1 17 6	Sept. 30, 1918.— ,, One year's interest to June, 1918,	3 15 0
,, Balance to Credit,	102 10 0		
	£106 5 0		£106 5 0

BALANCE SHEET.

To Life Subscription Account,	£219 5 0	By Investments:—		
,, Mr. Charles R. Cowie's Donation and accrued Interest,	102 10 0	Three 6 per cent. Exchequer Bonds of £50 each, repayable 16th February, 1920,	£150 0 0	
,, Capital,*	480 1 7	Two 5 per cent. Exchequer Bonds of £50 each, repayable 1st December, 1920,	100 0 0	£250 0 0
		,, Property:—		
		Books in the Library,	£440 0 0	
		Furniture, Bookcases, Microscope, &c.,	60 0 0	500 0 0
		,, Cash in Bank,	£38 4 6	
		,, Do. in Hand,	13 12 1	51 16 7
	£801 16 7			£801 16 7

* NOTE.—Subject to cost of publishing *Transactions*.

GLASGOW, 13*th November*, 1918.—Examined, compared with relative Vouchers and Securities, and found correct, the Balance in Hon. Treasurer's hands being Thirteen Pounds Twelve Shillings and One Penny.

JAMES L. BEGG, *Hon. Treasurer*.

(Signed) ALEXANDER M'LEAN, ARCH. MACINTYRE, } *Auditors*.

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THE GEOLOGICAL SOCIETY OF GLASGOW.

Office-Bearers for Session 1919-1920.

President—

Dr. Robert Kidston, F.R.S.

Vice-Presidents—

Peter Macnair, F.G.S. (*retires* 1920).
William R. Smellie, M.A., D.Sc. (*retires* 1921).
James L. Begg (*retires* 1922).

Members of Council—

M. M'Gregor, M.A., B.Sc. C. M. Leitch, B.Sc. Alex. Wallace.
James Hamilton. James Neilson. Alex. Stevens, M.A., B.Sc.
J. G. Roberts. Robert W. Dron. Arthur Shute.
Herbert Priestley. James Stark. D. N. M'Arthur, B.Sc.

Honorary Secretaries—

David B. Duncanson, B.Sc., Training College, Glasgow.
G. W. Tyrrell, A.R.C.Sc., University, Glasgow.

Honorary Librarian—

William Sinclair, 47 Oswald Street, Glasgow.

Honorary Treasurer—

James L. Begg, 13 Weirwood Park, Baillieston.

COMMITTEES APPOINTED BY COUNCIL.

Finance Committee—

Charles R. Cowie, James Stark, Arch. M'Intyre, James L. Begg, *Convener.*

Printing and Publishing Committee—

Professor Gregory, Arthur Shute, R. W. Dron, G. W. Tyrrell, *Convener.*

Library Committee—

Alex. M'Lean, James Stark, D. N. M'Arthur, Wm. Sinclair, *Convener.*

Excursions Committee—

Professor Gregory, Alex. Stevens, G. W. Tyrrell, M. M'Gregor, D. N. M'Arthur, C. M. Leitch, *Convener.*

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LIST OF MEMBERS.

(As at 9th April, 1920.)

Non-Resident Honorary Members.

Year of Election.

1863. Geikie, Sir Archibald, D.C.L., LL.D., F.R.S., &c., Shepherd's Down, Haslemere, Surrey.

1867. Woodward, Henry, LL.D., F.R.S., 13 Arundel Gardens, Notting Hill, London, W.

1883. Teall, Sir J. J. H., D.Sc., F.R.S., 174 Rosendale Road, Dulwich, London.

1908. Bonney, T. G., Sc.D., LL D., F.R.S., 9 Scroope Terrace, Cambridge.

1909. Hind, Wheelton, M.D., B.S., F.R.C.S., Roxeth House, Stoke-on-Trent.

1917. Harker, Alfred, M.A., F.R.S., St. John's College, Cambridge.

1918. Lacroix, Professor A.

1918. Daly, Professor R. A., Harvard, Cambridge, Mass., U.S.

1918. Cole, Professor G. A. J., F.R.S., Orahova, Carrickmines, Co. Dublin.

Resident Honorary Members.

1900. Gray, Mrs. Robert, 59 George Street, Edinburgh.

1902. Horne, John, LL.D., F.R.S., 20 Merchiston Gardens, Edinburgh.

1907. Murdoch, Mrs. J. B., Capelrig, Newton Mearns, Renfrewshire.

1902. Peach, B. N., LL.D., F.R.S., Geological Survey Office, Edinburgh.

1909. Smith, John, Dykes, Dalry, Ayrshire.

1918. Flett, J. S., M.A., D.Sc., H.M. Geological Survey, Edinburgh.

1918. Macconachie, J. S., H.M. Geological Survey, Edinburgh.

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Corresponding Members.

Year of Election.

1864. Mitchell, Rev. Hugh, LL.D., Craig, Montrose.
1867. Kerr, David, Wemyss Colliery, Fifeshire.
1871. Jack, R. L., LL.D., F.G.S., 36 Overstrand Mansions, Battersea Park, London.
1871. Jamieson, T. F., F.G.S., Ellon, Aberdeenshire.
1883. Scott, Thomas, F.L.S., Menzies Road, Torry, Aberdeenshire.
1884. Dobbie, Sir J. J., M.A., D.Sc., F.R.S., 4 Vicarage Gate, Kensington, London, W.
1884. Nathorst, Professor Alfred Gabriel, Stockholm, Sweden
1898. Livingston, Colin, Ardtraigh, Fort-William.
1909. Young, James, Lesmahagow.
1916. Black, Geo. F., New York Public Library, New York, U.S.A.

Ordinary Members.

[An asterisk (*) indicates a Life Member.]

1905. Anderson, E. M., M.A., B.Sc., H.M. Geological Survey Office 33 George Square, Edinburgh.
1914. Anderson, James, 205 Albert Road, Pollokshields.
1908. Anderson, P. J., M.A., LL.B., University Library, Aberdeen.
1912. Andrew, John, School House, Renton.

1919. Bailey, E. C., M.C., B.A., F.G.S., 33 George Square, Edinburgh.
1898. Bain, James, The Whins, Alloa.
1894. *Barr, Archibald, D.Sc., LL.D., Mugdock, Milngavie.
1903. Beattie, William, Dineiddwg, Milngavie.
1905 *Begg, James L., 13 Weirwood Park, Baillieston.
1916. Begg, Mrs. J. L., 13 Weirwood Park, Baillieston.
1914. Borland, James, 8 Barns Street, Ayr.
1912. Brodie, Matthew S., 39 Wellmeadow, Paisley.
1914. Brown, A. J., Hope Street, Glasgow.
1914. Brown, James, Broomside, Manse Road, Motherwell.
1914. Brown, John, Beansburn, Kilmarnock.
1904 Buchanan, R. M'Neil, M.B., C.M., F.F.P.S.G., Corindi, Scotstounhill, Glasgow.

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Year of Election.

1894. Burnett, Sir John James, R.S.A., LL.D., 70 University Avenue, Hillhead, Glasgow.

1902. Burns, Professor Daniel, M.Inst.M.E., Technical College, George Street, Glasgow.

1906. Carruthers, R. G., F.G.S., H.M. Geological Survey Office, 33 George Square, Edinburgh.

1895. Chalmers, David, 3 Winston Avenue, Broomhill, Glasgow.

1914. Chambers, R. S., Carbarns, Jerviston Road, Motherwell.

1918.. Coleman, W. H., 1 Athole Gardens, Newlands.

1912. *Conacher, Harry R. J., Horsewood Road, Bridge of Weir.

1891. Cowie, Charles R., Woodend, Partickhill, Glasgow.

1900. *Cozens, Samuel F., Salem, Skelmorlie.

1894. Dixon, Walter, Derwent, 30 Kelvinside Gardens, Glasgow.

1916. Dollin, P. E., 1 Balraird Drive, Rutherglen.

1907. Donald, W., The Eglinton Silica Brick Company, Ltd., Dundyvan, Coatbridge.

1881. *Dougan, John, 27 Smith Street, Hillhead, Glasgow.

1918. Douglas, W. P., Redholme, Hillpark, Glasgow.

1920. Dow, Eric, 26 Bute Gardens, Hillhead.

1895. Dron, R. W., M.Inst.C.E., 65 Renfield Street, Glasgow.

1913. *Duncanson, David B., B.Sc.(Lond.), 19 King Edward Road, Jordanhill, Glasgow.

1883. Dunlop, Robert, Woodmill Road, Dunfermline.

1914. Dunn, George Loudon, Annanhill, Kilmarnock.

1914. Dunn, H. Shaw, 40 Highburgh Road, Dowanhill, Glasgow.

1901. Du Toit, Alex. L., B.A., F.G.S., Irrigation Department, Pretoria, South Africa.

1914. Edwards, E. J., M.Sc., Royal Technical College, Glasgow.

1918. Ellis, David, D.Sc., Birchtor, Milngavie.

1901. Faill, John, 7 Winton Drive, Kelvinside, Glasgow.

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Year of Election.

1911. Falconer, J. D., M.A., D.Sc., F.G.S., F.R.S.E., Lecturer on Geography, The University, Glasgow.
1914. Feeley, Wm., 127 Glebe Street, Glasgow.
1898. Fergus, A. Freeland, M.D., 22 Blythswood Square, Glasgow.
1915. Fletcher, W., West View, Scott Street, Hamilton.
1915. Fraser, J. M., 169 Berkeley Street, Glasgow.
1898. *French, Thomas, 1 Kelvinside Terrace, Kelvinside, Glasgow.
1919. Frew, James, 180 Hope Street, Glasgow.
1914 Fyfe, D. W., 11 Melrose Gardens, Glasgow

1901. Gale, William M., C.E., 18 Huntly Gardens (West), Glasgow.
1887. Gardner, John, 65 Great Clyde Street, Glasgow.
1919. Garven, Alex. B., Dunblair, Kilmarnock.
1912. Gilchrist, Percy C., 18 Priory Road, Hornsey, London.
1908. Gilmour, Matthew B., Saffronhall House, Hamilton.
1873. *Gilmour, Thomas, M.D., Port Ellen, Islay.
1877. *Graham, M. M., 21 Bath Street, Glasgow.
1904. *Gregory, John Walter, D.Sc., F.R.S., F.G.S., Professor of Geology, Glasgow University.
1917. Gregory, Christopher J., 4 Park Quadrant, Glasgow.

1907. Hall, Rev. Charles A., F.R.M.S., Meersbrook, Meikleriggs, Paisley.
1915. Hamilton, James, 53 Bothwell Street, Glasgow.
1913. *Harrison, John V., B.Sc., 34 Rowallan Gardens, Glasgow.
1916. Hawkes, Leonard, M.Sc., Southview, Holmwood Grove, Jesmond, Newcastle.
1908. Hendry, David, Dunmore, Thomson Avenue, Johnstone.
1917. Henry, Archibald, 11 Clifford Street, Ibrox, Glasgow.
1912. Herdsman, W. H., 141 Bath Street, Glasgow.
1903. Hill, Alexander, 11 Dolphin Road, Pollokshields, Glasgow.
1919. Hill, James, M.A , 20 Neilson Street, Bellshill.
1877. Hislop, George R., F.C.S., F.R.S.E., Greenhill House, Paisley.
1919. Hood, Arch., M.A., Sherwood, Glenburn Road, Bearsden.

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Year of Election.

1914. Howat, William, The Cottage, North Motherwell.

1894. Hubbard, Walter Raglan, 9 Broomhill Avenue, Partick, Glasgow.

1908. Hunter, George, M.Inst.M.E., Mining College, Wigan.

1901. Hunter, William, Rosemount, Ledard Road, Langside, Glasgow.

1903. Hurll, Mark, Redholm, Temple, Glasgow.

1911. *Innes, Peter, 5 Ibrox Place, Paisley Road (West), Glasgow.

1915. Johnston, J. J. Hunter, Oakfield, Lenzie.

1918. Jones, T. S., Calderbank, by Airdrie.

1917. Keay, Miss G. L., 31 Melville Street, Glasgow.

1901. Kemp, William, c/o Mrs. Brown, 1 Kelvinside Terrace (West), Glasgow.

1908. Kerr, Andrew C., c/o Carron Company, 125 Buchanan Street, Glasgow.

1908. Kerr, David, Lynnewood, 140 Bo'ness Road, Grangemouth.

1890. Kidston, Robert, LL.D., F.R.S., 12 Clarendon Place, Stirling.

1882. King, Hugh B., Glenburn Hydro., Rothesay.

1882. King, Robert C., Solicitor, Ledcameroch, Kilwinning.

1907. *Knight, James, M.A., D.Sc., F.R.S.E., F.G.S., F.C.S., Queen's Park H.G. School.

1916. Leitch, Colin M., B.Sc., 223 New City Road, Glasgow.

1908. Leitch, P. Arthur, Haxtonn, Bothwell.

1914. Lewin, Harry W., Civil and Mining Engineer, 154 West Regent Street, Glasgow.

1916. MacArthur, D. N., B.Sc., 28 Grafton Street, Glasgow.

1896. M'Cowan, Donald, Dundashill House, Port-Dundas, Glasgow.

1899. M'Creath, George W., M.E., 208 St. Vincent Street, Glasgow.

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Year of Election.

1904. M'Creath, William, C.E., M.Inst.M.E., 208 St. Vincent Street, Glasgow.
1908. M'Donald, David P., M.A., B.Sc., S. A. School of Mines and Technology, Johannesburg.
1919. M'Gill, Dr. James, Coylton, Ayrshire.
1867. M'Glashan, John, 114 Candleriggs, Glasgow.
1910. M'Gregor, Murray, M.A., B.Sc., H.M. Geological Survey, 33 George Square, Edinburgh.
1904. Macintyre, Arch., F.S.A.A., Muirbrow Chambers, Hamilton.
1920. M'Kinven, Charles, 1 Love Street, Paisley.
1877. Maclay, Bailie William, F.G.S., Thornwood Hall, Langside.
1903. M'Lean, Alexander, 466 St. George's Road, Glasgow.
1917. MacMillan, Robert, M.A., B.Sc., 22 Eglinton Terrace, Ayr.
1895. Macnair, Peter, F.R.S.E., F.G.S., Art Galleries and Museum, Kelvingrove, Glasgow.
1897. *M'Neil, Charles, 1 University Gardens, Glasgow.
1914. M'Queen, David P. H., 7 Stewartville Gardens, Wishaw.
1916. M'Robert, Lady, B.Sc., Douneside, Tarland, Aberdeenshire.
1914. M'Vean, Duncan A., M.A., 213 Crow Road, Broomhill.
1883. M'Whirr, John, J.P., 3 St. John's Road, Cathcart, Glasgow.

1917. Main, James, Bonnybridge.
1887. Main, John, F.G.S., 24 Marlborough Avenue, Partick.
1894. Mann, Ludovic M'Lellan, F.S.A.(Scot.), 144 St. Vincent Street, Glasgow.
1920. Meldrum, Miss Agnes, 8 Fitzroy Place, Glasgow.
1915. Miller, Alfred G., West View, Strathmore Road, Hamilton.
1918. Milligan, A., c/o Mrs. Martin, 8 Steven Drive, Linthouse.
1881. *Mitchell, G. A., 5 West Regent Street, Glasgow.
1904. Moore, Quintin, Garrowbank House, Riddrie.
1877. Moore, Robert T., D.Sc., C E., 142 St. Vincent Street, Glasgow.
1916. Morrison, Miss M., 40 Rhannan Road, Cathcart, Glasgow.
1908. *Morrison, James, 87 East Princes Street, Helensburgh.
1900. *Muirhead, John, 13 St. John's Drive, Pollokshields, Glasgow.

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Year of Election.

1898. Munro, Alexander, 2 Royal Crescent, Queen's Park, Glasgow.

1894. *Murdoch, Robert, 91 Maxwell Road, Pollokshields, Glasgow.

1907. *Murdoch, J. A. W., Capelrig, Dunblane.

1870. *Murray, David, LL.D., 169 West George Street, Glasgow.

1907. Murray, Andrew G., c/o Brownlie, Watson & Beckett, 225 West George Street, Glasgow.

1907. Neilson, Miss Agnes T., 41 West Cumberland Street, Glasgow.

1891. *Neilson, James, 53 Wellshot Drive, Cambuslang.

1894. *Neilson, James, 116 Bishop Street, Port-Dundas, Glasgow.

1915. Patton, Donald, M.A., B.Sc., Manse Villa, Pollok Road, Shawlands, Glasgow.

1918. Pearson, Miss C. M., Beechdale, Alloa.

1920. Peacock, Miss Sarah, 8 Fitzroy Place, Glasgow.

1891. Pollok, Arthur, Kirkland, Bonhill, Dumbartonshire.

1910. Preston, Frank A. B., 16 Waverley Park, Shawlands, Glasgow.

1910. Priestly, H., 8 Glenview, Paisley.

1873. Rankine, David, C.E., 238 West George Street, Glasgow.

1902. Reoch, James W., Anglo-Persian Oil Co., 23 Great Winchester Street, London.

1911. Roberts, J. G., Trees Cottage, Barrhead.

1914. Robinson, P. J., A.M.Inst.C.E., Moverons, Allanshaw Street, Hamilton.

1910. Romanes, Mrs. J., Broompark, Helensburgh.

1875. *Rottenburg, Paul, LL.D., Holmhurst, Dowanhill Gardens, Glasgow.

1920. Scobie, Miss Edith A., 689 Shields Road, Pollokshields.

1912. Scott, Alexander, M.A., D.Sc., Central Technical School, Stoke-on-Trent.

1897. Shanks, Arch., 5 Green Lodge Terrace, Greenhead, Glasgow.

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1910. Shute, Arthur E., 4 Holyrood Crescent (West), Glasgow.
1887. *Sinclair, William, 47 Oswald Street, Glasgow.
1889. Sloan, Samuel, M.D., 5 Somerset Place, Sauchiehall Street, Glasgow
1911. Smellie, Wm. R., M.A., D.Sc., Mayfield Villa, Mossend.
1908. Smith, Duncan, F.F.S., Laurelbank, Arkleston Road, Paisley.
1912. Smith, John, Alton Mead, Sudhill Road, Paisley.
1887. *Somerville, Rev. James E., B.D., Castellar, Crieff.
1917. Sommerville, C. R., 26 Gassie Street, Shawlands.
1917. *Spiers, A. A. Hagart, D.L., J.P., Elderslie, Renfrewshire.
1896. Stark, James, 13 Princes Gardens, Partick, Glasgow.
1881. Steel, James, 37 Prince Edward Street, Crosshill, Glasgow.
1918. Stein, Norman, Castlecary, by Bonnybridge.
1919. Stein, Major Allan, M.C., Castlecary.
1912. Stevens, Alexander, M.A., B.Sc., Fresgoe, Reay, by Thurso.
1916. Stewart, Miss E., 16 West Princes Street, Glasgow.
1919. Stewart, Edward J. A., M.A., B.Sc., 8 Manor Road, Jordanhill.
1906. Stewart, Robert D., Belinda Cottage, Hillview Street, Shettleston, Glasgow.
1878. Stewart, Thomas, St. George's Chambers, Cape Town, South Africa.
1916. Sutherland, A., 12 Regent Park Terrace, Strathbungo.
1914. Sutherland, J. R., M.Inst.C.E., Engineer's Office, 45 John Street, Glasgow.
1920. Swinton, William E., 4 Craigpark, Denniston.

1917. Taylor, John, Castlecary.
1897. Thomson, Henry, 10 Princes Square, Strathbungo, Glasgow.
1917. Thomson, John R., Auchinlea Estate Office, Cleland, Lanarkshire.
1916. Trench, Miss J. B., M.A., B.Sc., 1 Springfield Terrace, Crossmyloof, Glasgow.
1906. Tyrrell, G. W., A.R.C.Sc., F.G.S., Geological Department, Glasgow University.

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1917. Wallace, A., 1 Dundas Cottage, Castlecary.
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1910. Watson, George C., 65 Chapel Street, Maryhill, Glasgow.
1919. Weir, John, Fireclay Co., Castlecary.
1901. Wight, E. Hall, 150 Hope Street, Glasgow.
1916. Wingate, John B., 208 St. Vincent Street, Glasgow.
1909. Wise, Thomas, Woodroyd, Barncleuth Road, Hamilton.
1912. Wordie, James M., B.A., B.Sc., Sedgwick Museum, Cambridge.
1881. Wotherspoon, David, 1108 Argyle Street, Glasgow.
1910. Wright, James, 36 Douglas Street, Kirkcaldy.
1911. Wyllie, B. K. N., M.A., B.Sc., Newmains, Caerlaverock, Dumfriesshire.

1902. Young, Arch. A., 2 Parkgrove Terrace (West), Glasgow.

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